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ESTIMATION OF PATIENTS' ORGAN DOSES AND CONCEPTUS DOSES FROM SELECTED X-RAY EXAMINATIONS IN TWO NIGERIA X-RAY CENTRES

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In this study, organ and conceptus doses of patients undergoing chest, abdomen and skull radiograph examinations at two Nigeria X-ray centres, Niger State General Hospital (NGH) and Two-Tees (TTX), are reported. Air kerma was measured, and entrance surface dose (ESD) and half-value layer estimated for each set of tube potential (kV_p), focus to skin distance and current–time product (mAs) used for each of the patients included in this study. Results show that the mean air kerma in the two centres are similar for the three projections considered in this study. Organ doses ranged from <0.01 to 2.18 mGy in NGH and from <0.01 to 1.29 mGy in TTX for examinations of the abdomen, from <0.01 to 0.20 mGy in NGH and from <0.01 to 0.13 mGy in TTX for examinations of the skull and from <0.01 to 3.90 mGy in NGH and from <0.01 to 1.96 mGy in TTX for examinations of the chest. Generally, no significant difference is seen between the organ doses of male and female patients. In NGH, organ doses are generally greater than those from TTX for the three examinations. The mean ESDs for examinations of the chest postero-anterior, abdomen antero-posterior (AP) and skull AP are, respectively, 5.37, 6.28 and 4.24 mGy in NGH, and 5.82, 5.33 and 4.76 mGy in TTX. The ESDs reported in this study, except for examinations of the chest, are generally lower than comparable values published in the literature. Conceptus doses were also estimated for female patients using normalised published conceptus dose data for abdomen examinations. The estimated conceptus doses were >1 mGy even when the conceptus was located 12 cm below the surface of the abdomen.

INTRODUCTION

The increasing use of X-ray facilities and equipment in hospital practice has made medical exposure an important source of radiation in the population collective dose[1]. Medical X-ray examinations are the largest contributor to the collective effective dose to the population from man-made ionising radiation sources[2]. In medicine, ionising radiation is used for two main purposes: diagnosis and therapy[3]. The use of ionising radiations for these purposes has been found to have benefits, but also detriments associated with the radiation doses incurred by patients being examined.

In view of the significant benefits from properly conducted medical exposures, the principal concern in radiological protection is how to reduce examinations that are either unlikely to be helpful to patient management or involve doses that are not as low as reasonably achievable (ALARA) in order to meet the specified clinical objectives. Therefore, there is a need to optimise X-ray equipment and radiological techniques[4]. Patient dose measurement, which usually reveals X-ray facilities with high doses, is an integral part of this optimisation procedure. The quantities that have been suggested for the assessment of patient doses include entrance surface dose (ESD), organ dose and effective dose. Most of the past patients' dose assessments in radiography have been based on ESD measurements[3,5–8]. ESD, however, cannot be directly used to assess the risk associated with diagnostic examinations. For the purpose of risk assessment, International Commission on Radiological Protection (ICRP) in 1977[9] recommended the determination of effective dose equivalent. In 1990, ICRP further recommended that patient exposures in diagnostic radiology be denoted by organ dose and effective dose; however, the preferred and most complete approach for risk estimation is accurate knowledge of all pertinent organ doses. Nevertheless, measurements of organ doses are complex, and it is often regarded as a troublesome job in diagnostic centres[10]. This may explain why there is scant information about organ doses of patients in diagnostic radiology.

In routine radiological examinations, it is not practical to conduct *in vivo* measurement of organ doses. Traditional methods used to calculate patient organ doses are based on implanting thermoluminescent dosemeters (TLDs) in tissues and organs positions' within a phantom consisting of tissue equivalent materials[11,12]. Monte Carlo simulation of photon interactions using computational models of the human body is another way by which organ doses can be obtained. The development of computational models started with the formulation of

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mathematical-equation-based stylised models[13–21] for which, despite all the efforts to improve them, the representation of a patient's body remained unrealistic[22]. The introduction of tomographic medical and magnetic resonance imaging techniques has, however, made possible the development of anatomically realistic models, many of which are currently in existence[23–31]. A detailed review of computational models that mimic human body has been presented by Zaidi and Xu[22]. Apart from using Monte Carlo simulation, conversion factors for obtaining organ doses from measured ESD are also now available in the literature[32–34].

In this study, using conversion factors in the US Centre for Device and Radiological Health (CDRH) document, organ doses from two diagnostic centres in Nigeria are presented. The results from this study complement the already existing, but scanty, database of organ doses in diagnostic radiology. To the best of authors' knowledge, this is the first time organ doses are being reported from any diagnostic centre in Nigeria. Further review of global practice, with respect to radiological examinations, has also been recommended[1] in order to obtain a refined assessment of worldwide exposures. The data presented in this study are also added to the database of information needed for this refined assessment of worldwide exposures. Organ doses included are those from skull antero-posterior (AP), chest postero-anterior (PA) and abdomen AP examinations.

Table 1. Personnel and specific data of X-ray machines used in the centres.

	NGH	TTX
Manufacture	G.E.C. Medical, Machlett X-ray, UK	G.E.C. Medical, Machlett X-ray, UK
Model/type	Dynamax 40, Serial no. 0023	Roentgen 201
Year of installation	1991	1993
Inherent filtration	1.0 mmAl	1.5 mmAl
Added filtration	1.5 mmAl	No added filter
Target material	Tungsten	Tungsten
Target angle	12°	16°

MATERIALS AND METHODS

A total of 294 patients, who were randomly selected from among adult patients attending medical investigations in two radiological centres, were included in this study. The two X-ray centres are: Niger state General Hospital (NGH), Minna (located in the North Central part of Nigeria) and Two-Tees X-ray centre (TTX) Ibadan (in Western Nigeria). NGH was chosen as one of the study facilities because of the fact that most people in Minna prefer to make use of a government health care facility. The implication of this fact is that dose values obtained from this study for NGH to a large extent will represent a good estimate of population dose of patients undergoing radiological examinations in Minna. Furthermore, the inclusion of NGH will, to the best of authors' knowledge, be the first time this kind of measurements is being reported from a radiological centre in the northern part of Nigeria. The inclusion of TTX located in the region of Nigeria where regulatory activities have been generally known to be more frequent than in the northern region where NGH is located, especially before the establishment of Nigeria Nuclear Regulatory Authority, may indicate whether past regulatory activities have had any impact.

For each centre, available machine-specific data such as type, filtration and year of installation were recorded and presented in Table 1. Patients' distribution by sex for the three examinations is presented in Table 2. Summary of the technical parameters

Table 2. Mean (range) of radiographic data and patients' sex distribution in the X-ray centres.

Examination	Centre	Radiographic data			Patients'sex distribution	
		Tube potential (kV_p)	Current–time product (mAs)	Focus to skin distance (cm)	Male	Female
Abdomen AP	NGH	89.1 (70–90)	75.7 (35–80)	90.4 (90–92)	20	25
	TTX	93.5 (90–94)	90	120	24	25
	ALL	91 (70–94)	78 (35–80)	106 (90–120)	44	50
Chest PA	NGH	77.7 (70–80)	45.4 (45–50)	180.7 (180–184)	25	25
	TTX	87.9 (83–90)	23.9 (19–24)	147 (120–150)	25	25
	ALL	85.4 (70–90)	34 (19–50)	152(120–184)	50	50
Skull PA	NGH	79.2 (70–90)	63.4 (50–80)	90.3 (90–100)	25	25
	TTX	93.3 (90–94)	75	89.9 (89–91)	25	25
	ALL	83 (70–94)	70 (50–80)	90 (90–100)	50	50

Where no range is reported, it means a constant value (stated in the table) of that parameter was used for all the patients.

used for the patients included in this study is also presented in Table 2. The tube potential (kV_p) and current–time product (mAs) values for each examination was read directly from the control panel of the X-ray machine. In the two centres, the same field sizes of 35×35, 35×43 and 18×24 cm^2 were used for chest PA, abdomen AP and skull AP, respectively.

Organs doses for each patient were calculated by multiplying the measured air kerma by the appropriate conversion factor from the document published by the CDRH in 1988. The conversion factors were published as a function of half-value layer (HVL). This appropriate conversion factor is obtained by first calculating the HVL corresponding to the technical parameters used for the patient using the Xcomp5r code. This computer code is a DOS program, developed and written in BASIC programming language by Nowotny and Hyfer[35]. It uses the technical parameters (e.g. tube potential (kV_p), total filtration and type of filters) for which X-ray spectrum is desired as input. The output of the code includes HVL which is a parameter of interest in this study. Meyer *et al.*[36] have shown that this code can be relied upon for HVL calculations among other things. Once HVL is calculated, the conversion factor corresponding to this HVL, obtained from the CDRH document, is used for calculating the organ dose of the patient. The conversion factors listed in the CDRH document for chest PA, skull AP and abdomen AP were obtained from measurements made using field sizes of 35.6×43.2, 25.4×30.5 and 35.6×43.2 cm^2, respectively. For HVL values not included in the publication, the corresponding conversion coefficients were obtained by interpolation. The air kerma measurements were carried out using LiF TLDs which have been calibrated at the secondary standard dosimetry laboratory of the National Institute of Radiation Protection and Research, University of Ibadan. The chips were annealed at 400 °C for 1 h and cooled inside the oven at 80 ºC for 17 h before being used for measurements. Air kerma measurement was carried out for each set of tube potential (kV_p), focus to skin distance (FSD) and current–time product (mAs) used for the patients.

Conceptus doses were also estimated for female patients using the normalised conceptus doses published by Damilakis *et al.*[37] for abdomen examinations. The conceptus doses in TTX, where the total filtration is 1.5 mmAl, could not be calculated because there were no normalised doses listed in the publication for X-ray machines with total filtration <2.5 mmAl. This calculation is important for the assessment of conceptus risk in cases where the women involved were unaware of being pregnant, especially during the first post-conception weeks (say the first 4 weeks), at the time the X-ray examination was undertaken.

RESULTS AND DISCUSSION

Table 2 shows that of the 295 patients included in this study, 145 were from NGH with 75 females and 149 from TTX with 75 females. The summary of the technical parameters presented in Table 2 shows that for abdomen examination, the technical parameters used in NGH were generally lower than those used in TTX. The same is true for skull examination except the mean FSD in both centres is almost the same. These variations in technical parameters, no doubt, will be a contributory factor to any variation in patients' doses that may be observed between NGH and TTX. The summary of HVLs calculated using the technical parameters as input variables in the computer code Xcomp5r[35] is presented in Table 3. The table also shows the means and ranges of air kerma measured in the two centres. The measured air kerma values are mostly between 3.50 and 4.50 mGy.

Table 3. Summary of measured air kerma, calculated ESD and HVL.

Examination	Centre	Air kerma (mGy)		ESD (mGy)		HVL[a]	
		Mean	Range	Mean	Range	Mean	Range
Chest PA	NGH	3.65	2.53–4.54	5.37	3.72–6.67	2.80	2.50–2.90
	TTX	3.96	3.95–3.96	5.82	5.81–5.82	2.34	2.20–3.30
	NGH + TTX	3.81	2.53–4.54	5.60	3.72–6.67	2.56	2.20–3.30
Abdomen AP	NGH	4.65	1.54–12.34	6.28	2.08–16.66	3.26	2.50–3.30
	TTX	3.95	3.91–3.96	5.33	5.28–5.35	2.49	2.40–5.50
	NGH + TTX	4.28	1.54–12.34	5.78	2.08–16.66	2.85	2.40–3.30
Skull AP	NGH	3.29	0.66–8.12	4.24	0.85–10.47	2.86	2.50–3.30
	TTX	3.69	3.02–3.91	4.76	3.90–5.04	2.49	2.40–2.50
	NGH + TTX	3.49	0.66–8.12	4.50	0.85–10.47	2.68	2.40–3.30

[a]The HVLs are obtained using the Xcomp5r code.

This explains why the mean air kerma values, which are similar in the two centres for the three projections, are between 3.50 and 4.50 mGy.

Tables 4–6 give the organ dose summaries (mean, standard deviation and range), respectively, for examinations of the skull, chest and abdomen at the two centres. The ranges of organ doses in the tables show that in a given centre and for a given organ the range (maximum organ dose divided by the minimum organ dose) is mostly between 1 and 2. In few cases, there are large variations with range factors as high as 12. Generally, organ doses are higher in NGH than in TTX for the three projections. NGH doses are slightly higher than those of TTX for examinations of skull and chest; the differences are more pronounced (1.5–2 times) for examinations of the abdomen. One of the factors that may be responsible for higher doses in NGH is the use of lower tube potential in this centre. Other factors, as listed in Table 2, that might have contributed to the extent of the difference between the doses in the two centres are current–time product (mAs) and FSD. In the case of examinations of the abdomen, the use of lower FSD might have contributed to the higher doses in NGH while a lowering of dose came from the use of lower current–time product (mAs). Doses in NGH are significantly higher than in TTX possibly because the use of lower current–time product (mAs) did little to reduce organ doses. For examinations of the skull, mean FSD in the two centres are similar. The slight variation in the organ doses for this examination between the two centres may therefore mean that the effect of increase in dose with the use of lower tube potential is slightly compensated by the use of lower current–time product (mAs). One will also expect doses for examinations of the chest to be higher in NGH because of lower tube potential and higher current–time product (mAs) values; on the contrary the doses in the two centres are similar. A possible reason for this is that the use of higher FSD in NGH compensated for the higher doses from the use of lower tube potential and higher current–time product (mAs). These observed variations, in organ doses, within a centre and between the two centres in this study are within the level of variations that have been reported for patients' doses. In some previous reports, variations of up to a factor of 25 have been reported[3,6,7]. These variations, apart from the differences in technical parameters discussed above, might also have been partly due to several other factors including the difference in X-ray machine and patients' anatomy. Furthermore, records of regulatory activities, which have been analysed in previous studies[38,39], did not exist for NGH but for TTX. The interactions between the regulators and the radiologists of TTX during the regulatory activities could therefore have also to some extent

Table 4. Organ dose[a] (mGy) estimation for skull AP radiograph.

Organ	TTX			NGH		
	Male	Female	Male + female[b]	Male	Female	Male + female[b]
Lungs	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Active bone marrow	0.130 ± 0.001 0.127–0.131	0.131 ± 0.001 0.131–0.132	0.130 ± 0.0010 0.127–0.132	113 ± 0.0010 0.113–0.1140	167 ± 0.031 0.104–0.197	0.140 ± 0.041 0.104–0.197
Thyroid	0.088 ± 0.001 0.086–0.090	0.090 ± 0.001 0.090–0.091	0.089 ± 0.001 0.086–0.091	0.078 ± 0.001 0.078–0.079	0.125 ± 0.021 0.078–0.145	0.101 ± 0.032 0.078–0.145
Trunk tissue	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[a]For each organ, the first row gives the estimated mean organ doses, whereas the second row gives the range of the doses.
[b]Male + female means the doses were estimated using the data for both male and female patients.

Table 5. Organ dose[a] (mGy) estimation for chest PA radiograph.

Organ	TTX			NGH		
	Male	Female	Male + female[b]	Male	Female	Male + female[b]
Lungs	1.485 ± 0.217 1.134–1.957	1.551 ± 0.207 1.193–1.685	1.518 ± 0.212 1.134–1.957	1.609 ± 0.099 1.342–1.665	1.539 ± 1.247 0.338–3.895	1.574 ± 0.867 0.338–3.895
Active bone marrow	0.345 ± 0.079 0.049–0.392	0.306 ± 0.042 0.234–0.334	0.325 ± 0.066 0.049–0.392	0.411 ± 0.026 0.341–0.426	0.314 ± 0.025 0.071–0.798	0.362 ± 0.182 0.071–0.798
Thyroid	0.114 ± 0.022 0.083–0.178	0.113 ± 0.018 0.083–0.125	0.114 ± 0.020 0.083–0.178	0.142 ± 0.010 0.117–0.149	0.132 ± 0.098 0.029–0.315	0.137 ± 0.069 0.029–0.315
Trunk tissue	0.528 ± 0.074 0.407–0.682	0.444 ± 0.058 0.344–0.481	0.486 ± 0.0780 0.344–0.682	550 ± 0.034 0.468–0.578	0.436 ± 0.035 0.096–1.104	0.498 ± 0.025 0.096–1.104
Breast		0.170 ± 0.026 0.125–0.188			0.185 ± 0.015 0.042–0.417	
Ovaries		<0.01			<0.01	
Uterus		<0.01			<0.01	

[a]For each organ, the first row gives the estimated mean organ doses, whereas the second row gives the range of the doses.
[b]Male + female means the doses were estimated using the data for both male and female patients.

Table 6. Organ dose[a] (mGy) estimation for abdomen AP radiograph.

Organ	TTX			NGH		
	Male	Female	Male + female[b]	Male	Female	Male + female[b]
Lungs	0.053 ± 0.002 0.049–0.054	0.054 ± 0.002 0.049–0.056	0.054 ± 0.002 0.049–0.056	0.090 ± 0.003 0.021–0.108	0.087 ± 0.001 0.083–0.088	0.089 ± 0.002 0.021–0.108
Active bone marrow	0.174 ± 0.004 0.165–0.176	0.175 ± 0.004 0.165–0.176	0.175 ± 0.004 0.165–0.176	0.312 ± 0.098 0.069–0.664	0.305 ± 0.003 0.296–0.306	0.308 ± 0.066 0.069–0.664
Thyroid	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Trunk tissue	0.641 ± 0.116 0.615–0.646	0.643 ± 0.001 0.615–0.646	0.642 ± 0.001 0.615–0.646	0.932 ± 0.326 0.252–2.175	0.901 ± 0.006 0.882–0.902	0.915 ± 0.217 0.252–2.175
Testes	0.076 ± 0.002 0.071–0.077			0.122 ± 0.040 0.030–0.268		
Ovaries		0.947 ± 0.019 0.892–0.954			1.464 ± 0.012 1.420–1.468	
Uterus		1.279 ± 0.026 1.204–1.288			1.945 ± 0.016 1.893–1.950	

[a]For each organ, the first row gives the estimated mean organ doses, whereas the second row gives the range of the doses.
[b]Male + female means the doses were estimated using the data for both male and female patients.

improved the knowledge of the radiologists in TTX with respect of how to better optimise patients' examinations in order for the patients to incur doses ALARA.

A comparison of the organ doses from this study with those from UNSCEAR[40] is presented in Table 7. The UNSCEAR data were doses in organs and tissues from various diagnostic X-ray examinations in Japan for male patients. The doses in this study, except for thyroid, are generally higher than those from Japan. This observation may be due to possible differences in X-ray machines' configurations, patients' anatomy and the fact that the conversion factors used were obtained from measurements with field sizes that are larger than the ones used in this study. The contribution to the higher doses due to the used conversion factors can be understood from the fact that the ratios of the areas of the field sizes in the CDRH document to those used in this study are 1.26, 1.79 and 1.02 for chest PA, skull AP and abdomen AP, respectively; therefore, the organ doses must have been overestimated by factors close to these ratios.

Since organ dose data are very scarce, in order to compare the results of this study with recent measurements, the measured air kerma were used to

Table 7. Comparison of mean organ dose (mGy) used in this work and data in UNSCEAR[42].

	This work				UNSCEAR[42]
	TTX		NGH		
	Female (male)	Male + female	Female (male)	Male + female	
Chest (PA)					
Lungs	1.55 (1.49)	1.52	1.54 (1.61)	1.57	0.30
ABM	0.31 (0.35)	0.33	0.31 (0.41)	0.36	0.07
Thyroid	0.11 (0.11)	0.11	0.13 (0.14)	0.14	0.10
Breast	0.17	0.17	0.19	0.19	0.30
Ovary	<0.01	<0.01	<0.01	<0.01	
Testes	(<0.01)	<0.01	(<0.01)	(<0.01)	0.0001
Uterus	<0.01	<0.01	<0.01	<0.01	
Abdomen (AP)					
Lungs	0.05 (0.53)	0.05	0.09 (0.09)	0.09	0.004
ABM	0.18 (0.17)	0.17	0.31 (0.31)	0.31	0.002
Thyroid	<0.01	<0.01	<0.01	<0.01	0.002
Ovary	0.95	0.95	1.46	1.46	
Testes	0.08	0.08	0.12	0.12	018
Uterus	1.28	1.28	1.95	1.95	

Table 8. Comparison of mean ESD (mGy) calculated in this work with some published values and UK reference doses.

Examination	Centre	This work	Ogunseyinde *et al.*[7]	Ogundare *et al.*[3,6]	Ajayi and Akinwumiju[42]	1993 UK reference doses
Chest PA	NGH	5.37	0.2–4.5	—	0.4	0.3
	TTX	5.82				
Abdomen AP	NGH	6.28	—	2.0–14.0	3.0	10.0
	TTX	5.33				
Skull AP	NGH	4.24	5.2	—	3.0	5.0
	TTX	4.76				

Range is specified in cases where mean ESD was reported for more than one centre and/or room.

Table 9. Estimated conceptive dose for female patients in NGH.

Depth (cm)	4	6	8	10	12	14
Conceptive dose (mGy)	4.40 ± 0.02	3.29 ± 0.02	2.39 ± 0.02	1.73 ± 0.01	1.20 ± 0.01	0.82 ± 0.01

estimate ESDs for the three projections using the relation that ESD is the product of backscatter factor (BSF) and air kerma. The BSF values of 1.47, 1.35 and 1.29 assumed in this study for chest PA, abdomen AP and skull PA, respectively, were taken from the published work of Compagnone *et al.*[41]. The summary of the calculated mean ESDs are presented in Table 3. The mean ESDs for examinations of the chest PA, abdomen AP and skull AP are 5.37, 6.28 and 4.24, respectively, in NGH and 5.82, 5.33 and 4.76 mGy, respectively, in TTX. In Table 8, the calculated ESDs were compared with previous dosimetry measurements that have been reported for diagnostic radiology in Nigeria[3,6,7,42] and 1993 UK reference doses[43]. The ESDs reported in this study, except for examinations of the chest, are in most cases lower than comparable values published for some centres in Nigeria and the UK reference doses. In the case of examinations of the chest PA, the calculated mean ESD is very much higher than the UK reference doses, but not too different from mean ESDs reported by Ogunseyinde *et al.*[7] for two centres including TTX for which they reported a mean ESD of 4.5 mGy. Again the higher doses for examinations of chest PA compared with UK reference doses can be attributed to the use of technical parameters (e.g. lower tube potential (kV_p) and higher current–time product

(mAs)) that are different from those recommended for UK practices, different X-ray machines and variations in patients' anatomy.

The calculated conceptus doses for the female patients for the first post-conception weeks and for various possible depth of conceptus for which Damilakis *et al.*[37] provided conversion factor are listed in Table 9. The calculated conceptus doses are >1 mGy even when the conceptus is located 12 cm below the surface of the abdomen. This is contrary to a dose limit of 1 mGy per annum recommended for the public (since the fetus can be considered as a public in the situation of the examination).

CONCLUSION

Organ and conceptus doses from two diagnostic X-ray centres in Nigeria have been estimated using measured air kerma and conversion factors from CDRH document. The measured air kerma in the two centres were found to be similar for the three projections considered in this study. The organ doses, estimated using the air kerma values, ranged from <0.01 to 2.18 mGy in NGH and from <0.01 to 1.29 mGy in TTX for examinations of the abdomen, from <0.01 to 0.20 mGy in NGH and from <0.01 to 0.13 mGy in TTX for examinations of the skull and from <0.01 to 3.90 mGy in NGH and from <0.01 to 1.96 mGy in TTX for examinations of the chest. The calculated mean ESDs of 5.37, 6.28 and 4.24 mGy in NGH and 5.82, 5.33 and 4.76 mGy in TTX for examinations of the chest PA, abdomen AP and skull AP, respectively, were found to be mostly below previously reported values from measurements in some Nigeria X-ray centres and 1993 UK reference doses. The observed variations in the doses have been attributed to the use of different technical parameters, difference in X-ray machine and patients' anatomy. Conceptus doses estimated for female patients using normalised published conceptus dose data for abdomen examinations were found to be >1 mGy even when the conceptus was located 12 cm below the surface of the abdomen.

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