Available online at www.worldscientificnews.com

World Scientific News

An International Scientific Journal

WSN 161 (2021) 143-156 EISSN 2392-2192

Estimation of entrance skin dose and effective dose from abdomen radiography in two diagnostic facilities in Aba, Abia State, South-East Nigeria

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ABSTRACT

Medical exposure for abdomen radiography is associated with higher doses compared to X-Rays of the chest and other extremities. The study aims to determine the mean entrance skin dose (ESD) for 104 adult patients between 20-89 years with 2 X-Ray units (A and B) in Aba, South-East Nigeria and to determine the ESD at the 75th percentile to estimate the local diagnostic reference levels (LDRLs). This study also determined the effective dose (*E*), the dose area product (DAP) and the relationship between absorbed dose (*DT*) and other parameters. This study will also compare its findings with relevant articles where necessary. The study used 2 functional floors mounted X-Ray units. A total of 208 annealed thermoluminescent dosimeters (TLDs) were used made of Lithium Fluoride, doped with Magnesium and Titanium (LiF: Mg, Ti). Two TLD chips were used per patient. The chips were positioned at the anterior and posterior end of the patient respectively for a given beam area for abdomen radiography. After exposure, a calibrated RadPro TLDcube 400 reader (Freiberg Instrument, Germany) was used to estimate individual patient doses. This was done by multiplying the TLD counts by a pre-determined calibration factor (CF). The mean/75th percentile ESD for facilities A and B was 2.92/4.12 and 3.01/3.67 mGy. The *E* for facilities A and B was 0.73 and 0.82 mSv respectively. There was a good relationship between the *D*T with ESD, exit dose (ED) and DAP for facility A, but no relationship was seen with other parameters. The mean ESD was lower compared to the National Council on Radiation Protection and Measurements (NCRP 172) and the American Association of Physicists in Medicine (AAPM)

(Received 04 September 2021; Accepted 23 September 2021; Date of Publication 24 September 2021)

reports respectively. The study proved useful and could serve as a reference point to initiate LDRLs within the South-East zone in Nigeria for abdomen radiography.

***Keywords*:** Entrance skin dose (ESD), Local diagnostic reference levels (LDRLs), Dose area product (DAP), Effective dose (E), Absorbed dose (D_T), Thermoluminescent dosimeter (TLD), Kilovoltage peak (kVp), milliampere-seconds (mAs)

1. INTRODUCTION

Abdomen radiography comes with a higher radiation dose compared to the chest and extremity X-Ray [1, 2]. This is because organs in the abdomen are mostly soft tissues with low electron density and hence they require more milliampere-seconds (mAs) during imaging to better assess them. On the other hand, structures like the bones require fewer mAs to visualize them, this can be explained based on their differences in densities, which is directly related to their atomic numbers [3-5].

The entrance skin dose (ESD) is a dose indicator used for estimating the amount of radiation that is imparted on a patient or material (phantom) at the surface and can be determined on a patient or phantom using detectors like the thermoluminescent dosimeters (TLDs), ionization chambers, Gafchromic films or silicon photodiodes [6-8]. The use of TLDs is often a simple method for directly measuring ESD. Similarly, it can be determined indirectly using the patient and X-Ray parameters [9, 10].

It is, however, necessary that radiation dose for abdomen radiography be optimized with emphasis on proper collimation (Field size) and the appropriate selection of kVp and mAs factors [11, 12].

DRL is an investigational level used to determine unusually high radiation doses for common diagnostic medical X-Ray imaging procedures. DRLs are suggested action levels above which a facility should review its approach and determine if tolerable image quality can be achieved at lower doses [13-15]. DRLs are usually set at the 75th percentile (third quartile) of the measured patient or phantom data. The ICRP also emphasizes that DRLs should not be applied to individual patients. To make meaningful comparisons, mean data from different facilities should be compared against the benchmark DRL, with consistency in the protocol used [16].

The effective dose (E) is a parameter that is used to assess the potential for long-term effects arising from radiation exposure. For example, it is used for the estimation of lifetime cancer risk [17, 18, 37-39]. This study is aimed that determining the mean and the 75th percentile entrance skin dose (ESD) directly from abdomen radiography to adult patients between 20-89 days. It was also aimed at determining the effective dose (E), DAP and the relationship between absorbed dose (AD) and other parameters. Findings from this study were also compared to similar articles.

2. MATERIALS AND METHODS

This study was a prospective cross-sectional study designed to determine dose indicators (ESD, ED, D and DAP) during conventional abdominal X-Ray examinations in 2 privately owned diagnostic X-Ray centres denoted as A and B in Aba, Abia State using thermoluminescent dosimeters (TLDs).

Each participant was selected conveniently as they presented their request form to the radiographer on duty. The participants who met the inclusion criteria were enrolled in the study. Patients in distress/accident and emergency (A&E) cases, non-corporative patients and patients that refused to give consent were excluded from the study.

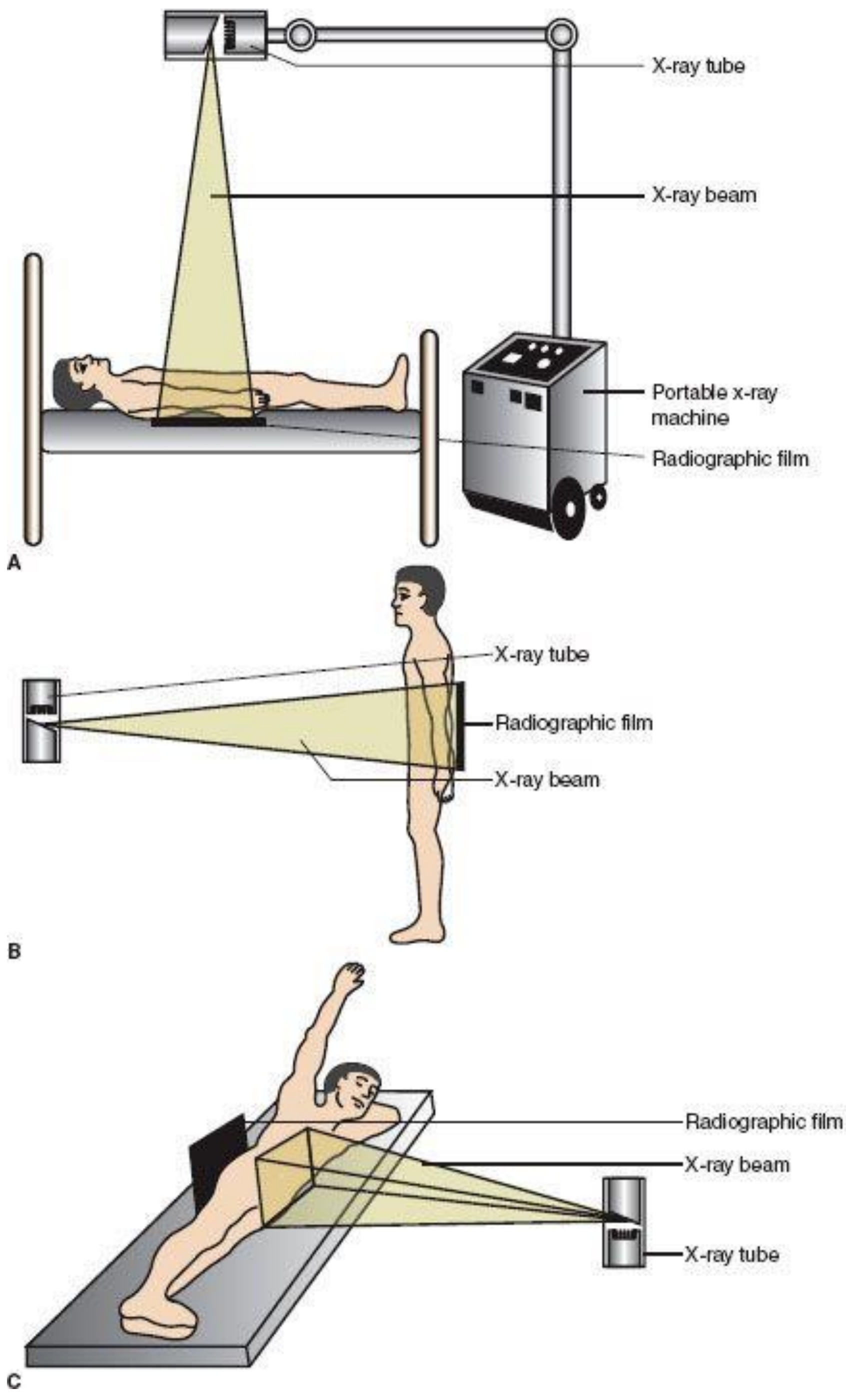

Figure 1. Different patient positions during abdomen radiography

In line with Helsinki Declaration, ethical approval was obtained from the ethical committee of each selected centre. The entire procedure was properly explained to all the prospective subjects and their consent was given before the commencement of the study. A total of 140 patients underwent conventional abdominal X-Rays from November 2020 to April 2021.

A single-phase static X-Ray machine (Philips Medical Equipment) was used in centre A with model number Philips DH 122. The maximum kilovoltage peak (kVp) and milliampere-seconds (mAs) was 150 and 200 respectively. The half-value layer and equivalent filtration were 2.9 and 3.5 mmAl.

The X-Ray machine in facility B was a static Siemens Medical Equipment with model number 1144096V2049. The maximum kilovoltage peak (kVp) and milliampere-seconds (mAs) was 150 and 320 respectively. The half-value layer and equivalent filtration were 2.7 and 3.2 mmAl.

A portable weighing scale was used to determine the weight of the patient in kilogram (kg). Similarly, a stadiometer was used to measure the height (H) of the patients in meters (m).

The body mass index (BMI) for each subject was calculated as:

$$BMI = \frac{\text{Weight (kg)}}{\text{H}^2(\text{m}^2)} \tag{1}$$

The Patient preparation for the abdominal X-ray examination was carried out by the Radiographer.

Other parameters that were considered as the patients' field sizes and patient thicknesses, the latter was determined by using the X-Ray collimator ruler from X-Ray focus to erect stand and X-Ray focus to patient skin. The patient was either made to lie in any of the 3 positions as shown in **Figure 1**.

Two TLDs was used per patient and they were positioned at the central axis of the beam anteriorly and posteriorly respectively. Two hundred and eight (208) thermoluminescent dosimeters (TLDs) made of Lithium Fluoride, doped with Magnesium and Titanium (LiF: Mg, Ti) was used. In other to effectively use the TLD chips, they were first annealed in a TLD Furnace Type LAB-01/400 at a temperature of 400 °C for one (1) hour and was allowed to cool to room temperature. To remove lower peaks they were heated to a temperature of 100 °C for another two (2) hours and were put to use after 48 hours **(Figure 2)**.

Parameters like the element correction factors (ECF) (0.9-1.1) and homogeneity of the TLD chips (< ±30%) were found to be within the acceptable range [19]. A RadPro Cube 400 manual TLD Reader (Freiberg Instruments GmbH, Germany) was used to determine the corresponding TLD count for the chips **(Figure 3)**.

Average background counts were obtained from three TLD chips that were not exposed to radiation (TL_0). Obtained TL counts (TL_i-TL_0) were multiplied with a pre-determined X-Ray calibration factor using the following equation [20, 21]:

$$\text{ESD} = (\text{TL}_i - \text{TL}_0) \times \text{CF}_{\text{Cs}-137} \left({}^{\text{mGy}}/_{\text{count}} \right) \tag{2}$$

where $TL_{i=1,2,3\ldots}$ is the count from the selected chips, TL_0 is the background count, CF is the calibration factor of the TL chips, which were calibrated with Cesium-137 (Cs-137) source.

Figure 2. Annealing oven (TLD Furnace Type LAB-01/400)

Figure 3. RadPro TLDCube 400 reader (Freiberg instrument Germany)

The patient effective dose (E) was calculated using the mathematical relation:

$$\text{Effective dose } (E) = \Sigma\ [\text{Tissue weighting factor } (W_T) \times \text{Equivalent dose } (H_T)] \quad (3)$$

The tissue weighting factor (W_T) was determined using the International Commission on Radiological Protection (ICRP) report 103 and the equivalent dose (H_T) was determined from the product of the absorbed dose and radiation quality factor for X-Ray [22].

Similarly,

$$\text{The Equivalent dose } (H_T) = \text{Quality factor (Q)} \times \text{Absorbed dose } (D_T) \quad (4)$$

In this case the radiation quality factor (Q) for X-Ray ≡ 1.

3. RESULTS

The distribution of 52 patients based on their age group was presented (**Table 1**). The age group with the highest number of the patient was 30-39 years, which was followed by those of 40-49 years. The least age groups were 20-29, 60-69, 70-79 and 80-89 years respectively. The mean FSD, field size, thickness, weight, height, BMI, kVp, mAs, ESD, ED, AD, DAP were 100.3 cm, 643.14 cm^2, 21.93 cm, 66.73 kg, 162.18 cm, 25.46 kg/m^2, 80 kVp, 16 mAs, 3.05 mGy, 1.02 mGy, 2.04 mGy and 1.94 Gy.m^2. The kVp and mAs used in facility A was uniform.

Table 1. Mean values per age group for facility A for abdomen radiography

N	FSD (cm)	Age (mean) (yrs)	Field size (cm^2)	T (cm)	W (kg)	H (cm)	BMI (kg/m^2)	kVp	mAs	ESD (mGy)	ED (mGy)	AD (mGy)	DAP (Gy.cm^2)
4	100.50	20-29 (23.50)	621	23.00	53.75	156.25	22.10	80	16	2.85	1.36	1.49	1.71
15	100.13	30-39 (34.47)	572	18.53	66.20	161.27	25.68	80	16	2.90	0.75	2.15	1.56
13	100.15	40-49 (44.85)	635	21.46	72.31	163.23	27.25	80	16	2.72	0.49	2.24	1.71
8	100.25	50-59 (56.25)	661	19.50	61.13	163.00	23.08	80	16	2.54	1.20	1.34	1.53
4	100.00	60-69 (63.25)	684	26.00	77.75	166.75	28.35	80	16	2.88	0.97	1.90	2.05
4	100.50	70-79 (73.25)	673	20.50	70.00	164.00	26.15	80	16	4.20	0.97	3.24	2.84
4	100.50	80-89 (82.75)	656	24.50	66.00	160.75	25.61	80	16	3.29	1.38	1.91	2.15

Also, the distribution of 52 patients based on their age group in facility B was presented (**Table 2**). The two age groups with the highest number of the patient were 30-39 and 40-49 years respectively. The two least age groups were 20-29 and 80-89 years respectively. The mean FSD, field size, thickness, weight, height, BMI, kVp, mAs, ESD, ED, AD, DAP were 100 cm, 967.74 cm^2, 23.92 cm, 73.09 kg, 162.25 cm, 27.79 kg/m^2, 90.07 kVp, 17.07 mAs, 2.92 mGy, 0.73 mGy, 2.18 mGy and 2.89 $Gy{\cdot}cm^2$. The kVp and mAs used in facility B were not uniform as noticed in A. However, uniform FSD was used for all age groups.

Table 2. Mean values per age group for facility B for abdomen radiography

N	FSD (cm)	Age (yrs) Range (mean)	Field size (cm^2)	T (cm)	W (kg)	H (cm)	BMI (kg/m^2)	kVp	mAs	ESD (mGy)	ED (mGy)	AD (mGy)	DAP ($Gy{\cdot}cm^2$)
5	100	24.6 (20-29)	851.8	20.2	55.6	155.6	22.91	85	17	2.16	0.46	1.702	1.85
10	100	35.9 (30-39)	1051.9	24.6	81	159	32.2	90	17	2.97	0.83	2.13	3.24
12	100	43.7 (40-49)	938.67	22.5	76.25	165.42	28.04	91	17	3.38	0.5	2.89	3.19
6	100	53.2 (50-59)	1070	25.67	72.5	164.17	26.79	90	17	3.51	0.61	2.9	3.72
8	100	64.1 (60-69)	1109.75	25.25	76.63	167.88	27.29	90	17	2.99	0.92	2.06	3.41
7	100	74.6 (70-79)	924.29	25	75.14	163.71	28.11	90.71	17.14	2.92	0.64	2.29	2.74
4	100	85.3 (80-89)	827.75	24.25	74.5	160	29.17	93.75	17.38	2.48	1.16	1.32	2.06

Comparison of the mean and 75th percentile ESD with other studies was presented in **Table 3.** The mean ESD in facility B was slightly higher than A. Also, the 75th percentile in facility A was higher compared to B. The ESD ranged from 0.78-12.72 mGy in facility A and 1.09-5.33 mGy in facility B. There was no statistically significant difference between the mean and 75th percentile ESD between A and B (P = 0.817). The mean ESD was compared to 7 national studies, 4 international studies and 2 recommended guidelines.

Table 3. Comparison of mean and 75th percentile ESD between this study and other relevant articles

	Mean ESD (mGy)	Mini ESD (mGy)	Max ESD (mGy)	3rd Quartile (mGy)
This study (Facility A)	2.92±1.88	0.78	12.72	4.12
This study (Facility B)	3.01±0.86	1.09	5.33	3.67
Aliasgharzadeh et al [23]	2.01	-	-	-

NCRP 172 [34]	12.6	4.99	36.6	3.40
Taha et al [24]	2.5±0.14	-	-	-
Musa et al [31]	4.29±0.51/ 4.77±0.25*	-	-	-
[a]Yacoob & Mohammed [35]	4.36/2.09/3.97	-	-	-
Nwokorie et al [32]	8.03	-	-	-
Osei & Darko [25]	1.82	-	-	-
AAPM/RSNA [33]	5.0	-	-	-
Olowookere et al [28]	3.2	-	-	-
Akpochafor et al [26]	2.57	-	-	-
Akinlade et al [29]	4.42-7.22	-	-	-
Zira et al [27]	1.01	-	-	-
Jibiri & Olowookere [30]	5.67	-	-	-

Mini = Minimum, Max = Maximum, * indirect method, [a]Mean ESD was compared to 3 X-Ray units

A Spearman correlation in facility A indicated that there was a relationship between the AD versus all dose indicators (ESD, ED and DAP). However, there was no relationship between AD and FSD, age, field size, patient thickness, weight, height and BMI. The relationship for kVp and mAs was not possible because both values were uniform **(Table 4)**.

Table 4. Spearman correlation for patient/machine parameters and dose indicators.

Parameters	P-value	Significance
AD vs. FSD	P = 0.127	No
AD vs. Age	P = 0.366	No
AD vs. Field size	P = 0.670	No
AD vs. Thickness	P = 0.899	No
AD vs. Weight	P = 0.085	No
AD vs. Height	P = 0.441	No
AD vs. BMI	P = 0.065	No

AD vs. kVp	-	-
AD vs. mAs	-	-
AD vs. ESD	P < 0.001	Yes
AD vs. ED	P < 0.001	Yes
AD vs. DAP	P < 0.001	Yes

A Spearman correlation in facility B indicated that there was a relationship between the AD and ESD and DAP but there was no relationship with the ED. There was no relationship between AD versus age, field size, patient thickness, weight and BMI except for the patient height. The Relationship for FSD was not possible because all values were uniform **(Table 5)**.

Table 5. Spearman correlation for patient/machine parameters and dose indicators in facility B

Parameters	P-value	Association
AD vs. FSD	-	-
AD vs. Age	P = 0.880	No
AD vs. Field size	P = 0.230	No
AD vs. Thickness	P = 0.489	No
AD vs. Weight	P = 0.922	No
AD vs. Height	P = 0.014	Yes
AD vs. BMI	P = 0.497	No
AD vs. kVp	P = 0.730	No
AD vs. mAs	P = 0.088	No
AD vs. ESD	P < 0.001	Yes
AD vs. ED	P = 0.259	No
AD vs. DAP	P < 0.001	Yes

The *E* in facility B (0.82 mSv) was higher comapared to A (0.73 mSv). The highest *E* was seen in a study in Nigeria. Similarly, the *E* in both facilities (A and B) was higher compared to the ICRP 60 and 103 reports **(Figure 4)**.

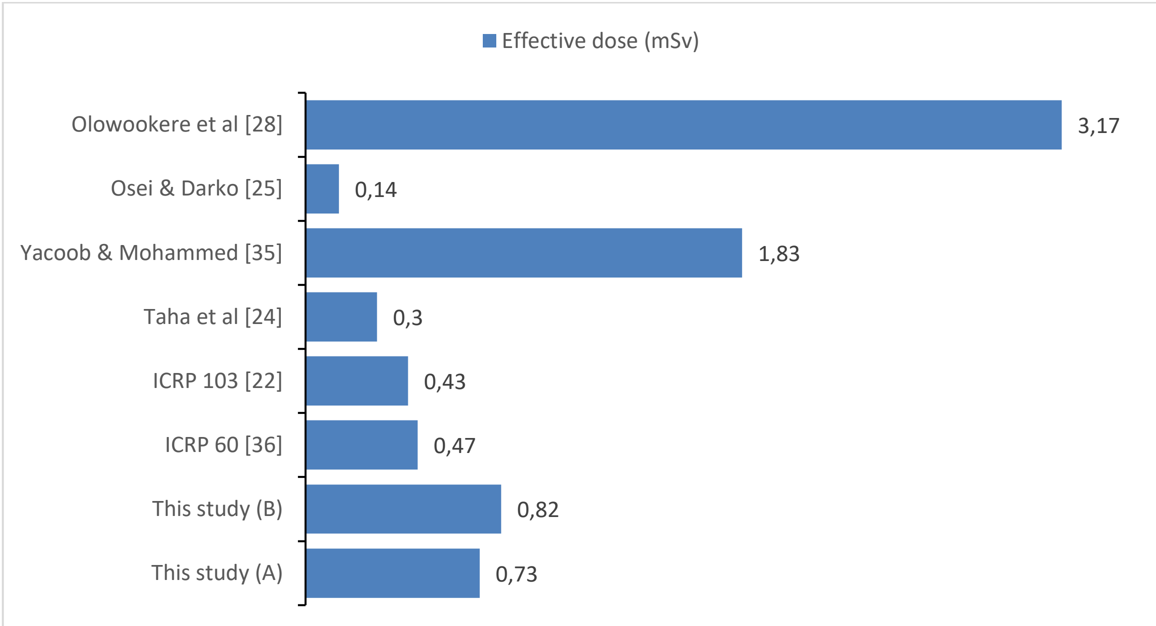

Figure 4. Comparison of effective dose (mSv) bewteen this study and other works

4. DISCUSSION

A study to determine the entrance surface dose from abdomen radiography has been carried out. The mean ESD for facilities A and B was 2.92±1.88 and 3.01±0.86 mGy. Also, the DAP was 1.79±1.09 and 3.02±1.44 Gy.cm^2. The 75th percentile ESD for facility A (4.12 mGy) was higher compared to facility B (3.67 mGy).

Furthermore, there were no association from spearman's correlation in facility A between the absorbed dose (AD) and patient related parameters for FSD (P = 0.127), age (P = 0.366), field size (P = 0.670), thickness (P = 0.899) weight (P = 0.085), height (P = 0.441) and BMI (P = 0.065) facility A. The kVp and mAs parameter in this study was uniform, so there was no correlation. However, there was relationship with other dose indicators like ESD (P < 0.001), ED (P < 0.001) and DAP (P < 0.001). Spearman's correlation in facility B showed good relationship between the absorbed dose (AD) and Height (P = 0.014), ESD (P < 0.001) and DAP (P < 0.001). Other parameters that showed no relationship was the age (P = 0.880), field size (P = 0.230) thickness (P = 0.489), BMI (P = 0.497), kVp (P = 0.730), mAs (P = 0.088) and ED (P = 0.259) respectively. The FSD parameter in this study was uniform, so there was no correlation.

The variation between the effective dose for facility A (0.82 mSv) and B (0.73 mSv) was < 10%, with facility A showing a higher value compared to B.

The mean ESD in this study (2.65 mGy) was higher compared to a study in Iran by Aliasgharzadeh et al, (2.01 mGy) [23]; Taha et al (2.5 mGy) [24]; Osei and Darko (1.82 mGy) [25]; Akpochafor et al (2.57 mGy) [26] and Zira et al (1.01 mGy) [27]. It was however lower compared to some studies in Nigeria by Olowookere et al (3.2 mGy) [28]; Akinlade et al (4.42 mGy) [29] and Jibiri and Olowookere (5.67mGy) [30], Musa et al (4.29 and 4.77 mGy) [31] Nwokorie et al (8.03 mGy) [32] and AAPM/RSNA (5.0 mGy) [33].

The technical parameters used, patient size and the methods (direct (use of TLDs) or indirect (calculation approach)) of estimating ESD are among factors identified to have affected dose. The 75th percentile ESD between this study (3.90 mGy) and NCRP 172 report (3.40 mGy) indicated that both results were close but the maximum ESD was noticed to be 36.6 mGy for NCRP 172, against our study which was 9.03 mGy [34]. The reason for this was because the NCRP 172 report covered several facilities compared to this study, which covered 2 facilities. Similarly, the variation in mean ESD between this study and the NCRP 172 report was 92%.

The mean effective dose (*E*) was lower compared to a study by Olowookere et al (3.17 mSv) [28] and Yacoob and Mohammed (1.83 mSv) [35]. On the other hand, it was higher compared to Taha et al (0.3 mGy) [24]; Osei and Darko (0.14 mSv) [25]; ICRP 60 (0.47 mSv) [36] and ICRP 103 (0.43 mSv) [22]. The mean *E* for both facilities (A and B) was 1.8 and 1.7 times higher compared to the *E* for ICRP 103 and 60 reports respectively. The effective dose is a parameter that is largely dependent on the ESD, so as the ESD increases, the effective dose would increase.

5. CONCLUSION

A study to determine the mean and 75th percentile ESD have been determined for abdomen radiography in Aba, Abia State using TLDs. Similar this study has determined the relationship between AD and other parameters and the *E* doses. The mean ESD was below the NCRP 172 and AAPM/RSNA reported doses, while the mean *E* for both facilities was 1.8 and 1.7 times higher compared to ICRP 103 and 60 reports respectively. The study can be used as baseline values to compare and initiate LDRLs in Abia State.

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