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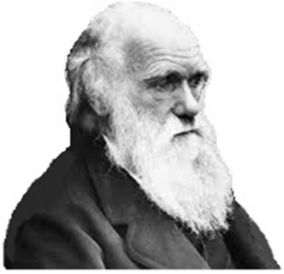

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Patient dose and lifetime cancer risk from contrast-enhanced radiography examination in a tertiary health institution in Delta State, South-South, Nigeria

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ABSTRACT

Contrast-enhanced radiography examination requires multiple exposures and may sometimes involve the patient receiving a higher radiation dose than expected. The study was aimed at determining the mean entrance skin doses (ESDs), dose area products (DAPs) and effective doses (E_{ff}) for 6 interventional procedures. The study was compared to similar guidelines and articles, with the aim of fashioning out a local diagnostic reference level in the region and it also determined the lifetime cancer risk for 3 out of the 6 contrast-enhanced procedures. The study used a 3-phase ceiling-mounted digital radiography (DR) X-Ray Unit (POLYRAD PREMIUM CS-Radiologia). A total of 140 investigations were carried out and the average patient age was 45.35 years. Patient doses were estimated using thermoluminescent dosimeters (TLDs) [Lithium Fluoride doped with Magnesium and Titanium (LiF: Mg, Ti)]. Patient ESDs and DAPs for barium enema (BE), barium meal (BM), barium swallow (BS), hysterosalpingogram (HSG), intravenous urogram (IVU) and micturating cystourethrogram (MCU) ranged from 7.51-12.01 mGy and 7.25-13.65 Gy.cm^2, while the effective doses (E_{ff}) ranged from 1.45-4.10 mSv. The DAP for BE, BM, BS and IVU was lower compared to the United Kingdom (UK), Ireland and Japan but HSG and MCUG were higher compared to the UK reports. The lifetime cancer risk for BS (46 per million) and IVU (114 per million) was comparable to the United Kingdom (UK) Health Protection Agency (HPA), while the lifetime cancer risk was doubled for BE compared to the UK HPA

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report. The study proved useful in areas where the use of contrast-enhanced radiography is still in use. The study has demonstrated that lower ESD and DAP can be achieved, which is comparable to the fluoroscopy modality.

Keywords: Entrance Skin Dose (ESD), Dose Area Product (DAP), Contrast-Enhanced Radiography, Ionization Chamber (IC), Thermoluminescent Dosimeter (TLD)

1. INTRODUCTION

Contrast-enhanced radiography examination is a special radiographic investigation that employs the use of contrast media to outline certain anatomical structures in the body [1-3]. Contrast-based examinations like barium enema (for large bowel), barium meal (for oesophagus, stomach and small bowel), barium swallow (for upper gastrointestinal (GI)), hysterosalpingography (for visualizing the uterus and fallopian tubes), intravenous urogram (IVU) (for visualizing the entire urinary system) and micturating cystourethrogram (MCUG) (for bladder and urethra abnormalities) are categorized as minimally invasive procedure [4-9].

There has been variation in patient doses with both radiography and fluoroscopy for contrast-enhanced examinations, which is largely dependent on the type of equipment used, hospital/regional protocols and the experience of the end user. In some cases, the detector may also influence the entrance skin dose (ESD) or the dose area product (DAP) outputs, while other studies have used mathematical software for patient dose estimation [10-17].

Due to technological advancement and the recent awareness of dose optimization, interventional radiology (IR) procedures with fluoroscopy now come with a variety of tools to help reduce patient dose in line with the principle of “as low as reasonably achievable (ALARA)”. While in radiography, flat panel systems (direct digital radiography) are used with automatic exposure control (AEC) systems to further reduce patient doses [18-20].

In many developing countries with protracted fluoroscopy downtime, conventional imaging is used and with a low level of quality assurance and control test, there is the likelihood for patient doses increasing [21, 22]. The use of appropriate technical factors (kilovoltage (kV) and milliampere seconds (mAs)), field sizes and appropriate focus to skin distances (FSD) and the experience of the radiographer/operator are contributory factors to patient doses [23, 24].

The dose-area product (DAP) could be used to measure the dose during the aforementioned procedures. The DAP is dose in the air multiplied by the field size. DAP is typically expressed in Gy.cm^2 [25]. Typically, a transparent flat ionization chamber (IC) mounted in the X-Ray tube assembly between the patient and the collimators are used to measure DAP. For patient DAP measurements, conventional radiography employs this method. The tube-housing cover conceals the DAP chamber in the majority of the most recent fluoroscopic instruments (flat panel or image intensifier) [26].

Thermoluminescent dosimeter (TLD) and optically stimulated luminescent dosimeter (OSLD) have been used to estimate the entrance skin dose (ESD) and can be converted to estimate the dose area product (Gy·cm^2) by taking note of the field size which is displayed on a DR unit [27].

The study was aimed at using TLDs with a ceiling-mounted direct digital (DR) X-Ray system (Radiologia) to estimate the mean ESD (mGy), DAP (Gy·cm^2), E_{ff} and lifetime cancer risk. Furthermore, results from this study were compared to other studies.

2. MATERIALS AND METHODS

The study used a ceiling mounted DR unit (POLYRAD PREMIUM CS-Radiologia, Madrid, Spain) (Table 1) and some basic quality assurance (QA) test was performed using a silicon photodiode and a current probe meter alongside a MagicMax basic unit (IBA Dosimetry, Germany), which has the capacity to measure practical peak voltage (PPV), mAs, mA, exposure time, filtration, half value layer, dose (mGy) and dose rate simultaneously (Figure 1 (a and b)) [28]. The TLD chip used was round phosphor called Lithium Fluoride, doped with Magnesium and Titanium (LiF: Mg, Ti), with batch number of RS/2146/19, diameter of 4.5 mm and thickness of 0.90±0.05mm, with sensitivity spread of ±3.5% standard deviation. Prior to this study, the TLD chips calibration factor was obtained from a Secondary Standard Dosimetry Laboratory (SSDL) in the National Institute of Radiation Protection and Research (NIRPB) in the University of Ibadan, Oyo State in Nigeria using a Cesium-137 source [29].

Before usage, the TLD chips were arranged on an annealing tray and were positioned in a TLD Furnace Type LAB-01/400 at a temperature of 400 °C for one (1) hour and were allowed to cool to room temperature. To remove lower peaks, they were heated to a temperature of 100 °C for another two (2) hour and were allowed to cool. They were later used after 48 hours for this study. Standard weighing scale and height meter with error level of ±0.05 was used to obtain the weight and height of the participants. A measuring tape from the X-ray unit was used to determine the patient thickness. This was done by subtracting focus to skin distance (FSD) from the focus to film distance (FFD). A paper tape was used to wrap the TLD chips and they were properly labelled.

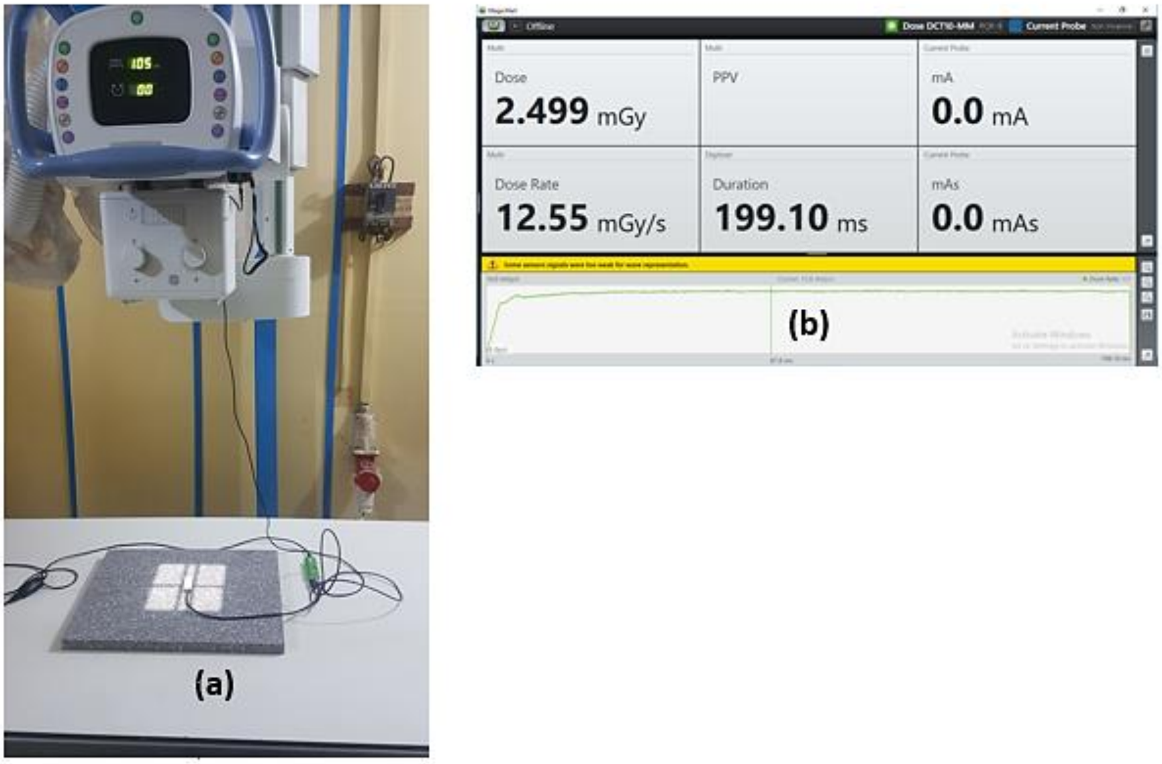
The following information were collected: patient's age, sex, weight, height, Body mass index, focus to film distance (FFD), field size and technical parameters (kVp and mAs). The following dose parameters were obtained after each examination: kVp, mAs, entrance skin dose (ESD) in mGy from readout of the TLDs and Dose area product (DAP) in Gy.cm^2. A total of 140 patients were considered for the 6 radiological procedures comprising of barium enema (BE), barium meal (BM), and barium swallow (BS), hysterosalpingography (HSG), intravenous urogram (IVU) and micturating cystourethrogram (MCUG).

Conventional Radiography: For each examination considered in this study, the TLD chips was placed on the patients at the center of the X-Ray beams central axis where the radiation strikes the patients skin and behind the patients at the exit of the beam. The exposed TLD was labeled (entrance surface dose and exit dose) for proper identification.

Table 1. Digital Radiography specification

Manufacturer	RADIOLOGIA
Type	Ceiling Mounted Unit (DR System)
Serial Number	19030007
Machine Model	POLYRAD PREMIUM CS
Power Capacity	50 kW

kVp Range	40-150 kVp
mAs Range	0.1-630 mAs
Maximum Current	3.5-1.6 A
Minimum Filtration	2 mm Al @75 kVp
Focal Spot	1.2/0.6
Grid	Yes (14×17 inches)
Total Filtration	3.3 mm Al
Line Voltage	115-240 V
Phase	3, 50/60 Hz
Target	Tungsten
Manufactured Date	February 2019



Dose 2.499 mGy

PPV

mA 0.0 mA

Dose Rate 12.55 mGy/s

Duration 199.10 ms

mAs 0.0 mAs

Figure 1. (a) Set-up for tube output, kVp, mAs, HVL measurements; **(b)** MagicMax display software from a PC.

The DAP was estimated using the relation [30]:

$$\text{DAP} = \frac{ESD}{BSF}\,FS$$

where the BSF was the backscatter factor. The assumed BSF (PMMA) was 1.52 for an average filed size of 625 cm^2 at 80kV and a filtration of 3.0 mmAl for the maximum field size, based on the International Atomic Energy Agency TRS 457 report [26] and FS was the area of the field size for individual focus to skin distance.

The patient effective dose (E) was determined using the mathematical relation [31]:

$$\text{Effective dose } (E_{ff}) = DAP \times F_h$$

where F_h is the conversion factor for the body part to be imaged. In the case of this study, the F_h for Barium meal and Barium swallow was $\cong 0.2$ and Barium enema, HSG, IVU and MCUG was $\cong 0.3$ [32].

2. 1. Data analysis

Statistical Package for Social Sciences IBM SPSS version 22 was used. A One-Way ANOVA, an Independent Sample t-Test and Pearson's correlation were used for data analysis. $P < 0.05$ was considered to be statistically significant and $P > 0.05$ was considered to be statistically not significant.

3. RESULTS

The results from the QA checks were within the acceptable range as indicated in the outcome section [33, 34]. Image quality assessment could not be performed due to the non-availability of test objects (Table 2).

Table 2. Test measurements of the X-Ray DR unit

Parameters	Average value	Recommended value	Outcome
kVp accuracy	0.15±0.07	±5	Pass
mAs accuracy	0.45±0.55	±5	Pass
Exposure accuracy	1.01±0.25	±10	Pass
mA accuracy	0.77±0.15	±10	Pass
Tube output (80kV)	54 µGy/mAs	52-69 µGy/mAs*	Pass
Exposure reproducibility	0.065	< 0.1	Pass
kVp reproducibility	0.0005	0.05	Pass

mAs reproducibility	0.0007	0.05	Pass
Tube leakage	5.37±0.73 µSv/hr	1000 µSv/hr	Pass
HVL @80kV	3.2±0.00	2.3	Pass
mA linearity	0.015	≤ 0.1	Pass

(Ref: AAPM Report 74 [33] and *IPEM [34])

Table 3 indicates the focus to field distance (FSD) which ranges from 120-150 cm, with the patient ages ranging from 36-54 years. The maximum field size was for barium enema (BE). The range of patient thicknesses ranged from for the 6 procedures ranged from 21-27 cm, the highest from HSG. The overall average for patient weight, height BMI, kVp and mAs was 75 kg, 1.7 m, 26 kg/m^2, 76 kV and 28 mAs. There was a statistically significant difference between the 6 groups of exams and the parameters ($P < 0.001$) from a One-Way Anova.

Patient ESDs and DAPs for barium enema (BE), barium meal (BM), barium swallow (BS), hysterosalpingogram (HSG), intravenous urogram (IVU) and micturating cystourethrogram (MCUG) ranged from 7.51-12.01 mGy and 7.25-13.65 Gy.cm^2, while the effective doses (E_{ff}) ranged from 1.45-4.10 mSv (Table 4).

Table 3. Patient and equipment parameters

Parameters	BE	BM	BS	HSG	IVU	MCUG
	N=15	N=10	N=10	N=35	N=35	N=35
FFD (cm)	120	120	150	120	120	120
Age (years)	44.20±14.83	51.9±16.45	54.2±12.75	36.37±4.04	42.71±10.61	42.69±17.98
Field size (cm)	1727±101	1780±152	1588±123	1630±94	1680±137	1590±217
Thickness (cm)	23.53±4.72	23.9±2.73	21.7±4.92	27.29±4.46	20.80±5.83	22.60±5.69
Weight (kg)	74.33±16.71	78.83±11.87	82.86±9.52	72.91±9.28	69.05±16.66	70.60±21.27
Height (m)	1.71±0.11	1.78±0.09	1.69±0.06	1.63±0.06	1.62±0.07	1.68±0.16
BMI	25.03±5.68	24.95±4.37	29.06±3.45	27.47±3.39	26.07±6.09	24.45±5.60
kVp	79.33±4.17	79.5±2.84	73.4±9.29	76.37±5.29	74.23±4.36	76.14±6.25
mAs	32.40±8.75	30.4±4.52	26.2±14.55	30.5±13.06	22.24±7.92	23.83±7.88

BE: Barium enema, BM: Barium meal, BS: Barium swallow, HSG: Hysterosalpingography IVU: Intravenous urogram and MCUG: Micturating cystourethrogram

Table 4. Mean ESD, DAP and E_{ff} dose measurements.

Exam	ESD (mGy)	DAP (Gy.cm^2)	E_{ff} (mSv)
BE	12.01±1.38	13.65±2.07	4.10
BM	7.82±1.72	9.16±2.13	1.83
BS	6.94±2.34	7.25±1.65	1.45
HSG	7.51±2.09	8.05±0.73	2.42
IVU	7.83±2.57	8.65±1.43	2.60
MCU	9.73±3.20	10.17±1.08	2.92

BE: Barium enema, BM: Barium meal, BS: Barium swallow, HSG: Hysterosalpingography IVU: Intravenous urogram and MCUG: Micturating cystourethrogram

Furthermore, Figure 2 shows the variation in DAP between this study and those of the United Kingdom (UK)-Health Protection Agency (HPA) report (Adopted 2016) [35], Health Information and Quality Authority (HIQA)-Ireland (2022) [36] and Japan (2020) report [37].

There was less comparison for HSG, IVU and MCUG.

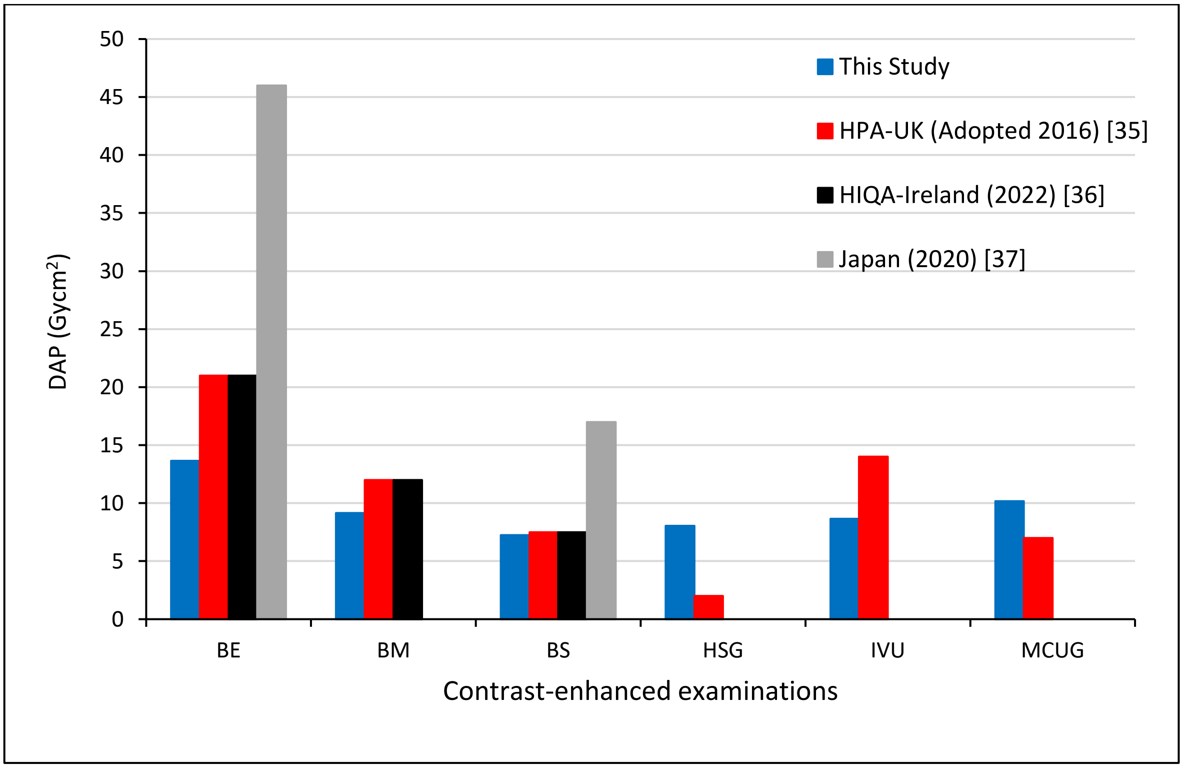


Figure 2. Comparison of DAP with recommended standard reports

There was a statistically significant difference in ESD between this study and Iacob *et al.* [13] (P = 0.003) and Zira *et al.* [38] (P = 0.0024) but no statistically significant difference was seen for Pataramontree et *al* (P = 0.130) [14] from an Independent Sample-t Test (Figure 3).

The DAP values were lower compared to Wambani *et al*. [10], Milu *et al.* [15], Spoelstra *et al.* [16], Delichas *et al.* [39], Nazlea *et al.* [40] and Ramsdale *et al.* [41] for most examinations (Table 5).

The kVp and mAs parameters between this study and Zira *et al.* [38] were comparable. Zira *et al.* used radiography and fluoroscopy, while Wambani *et al.* [10] were higher for the kV and lower for the mAs with the fluoroscopy unit (Figure 4).

In conclusion, the estimated lifetime cancer risk for BE, BS and IVU was compared to the HPA report [35]. The results show that there was no statistically significant difference between both risks (P = 0.4431). The highest compared risk was for BE.

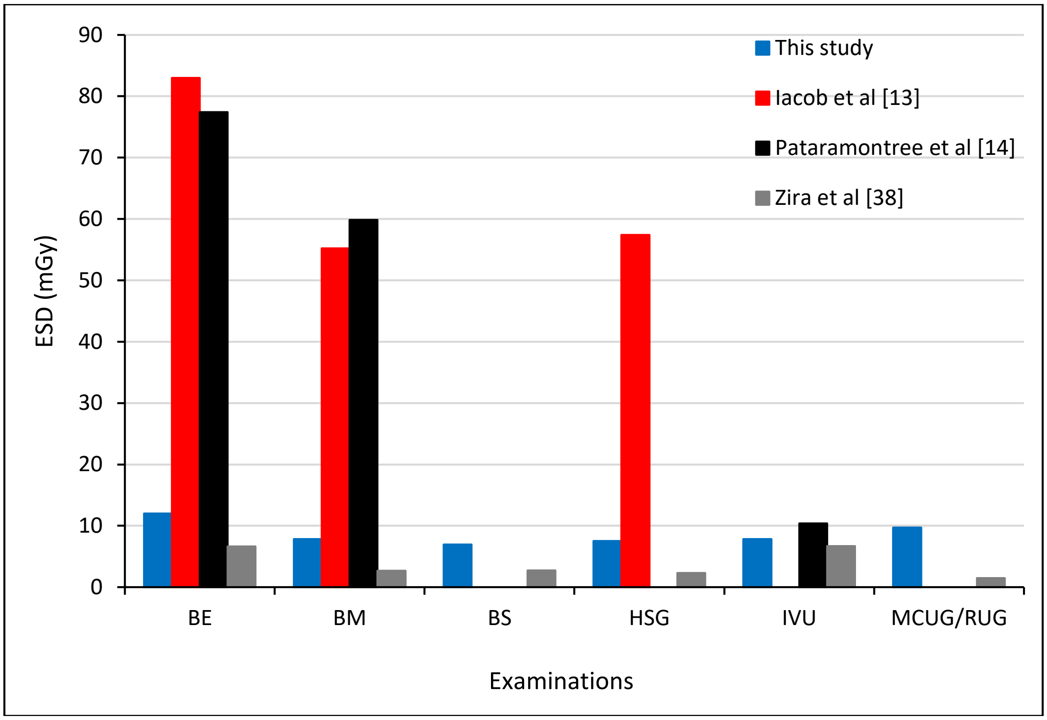


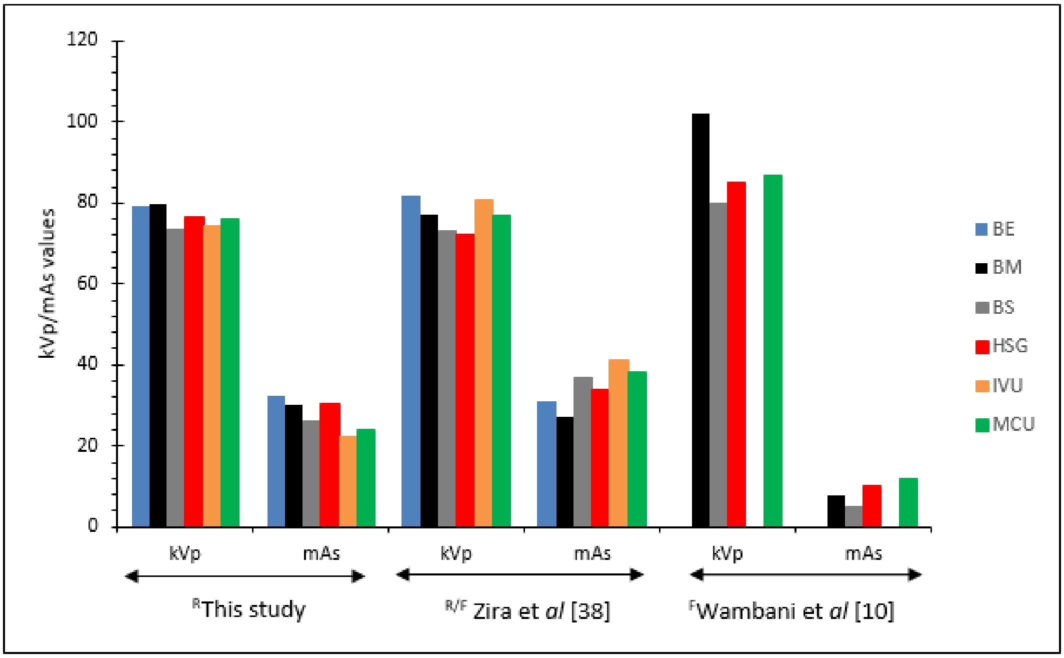
Figure 3. Comparison of ESD (mGy) with a similar studies

Table 5. Comparison of DAP (Gy.cm^2) with published articles

Examination	This study	[10]	[15]	[16]	[38]	[39]	[40]	[41]
BE	13.65	-	32.1	29	20.64	60	16	31.8
BM	9.16	61	20.5	21	8.98	25	17	11.7
BS	7.25	33	-	-	6.56	-	13	7.5

HSG	8.05	11	-	-	3.67	-	-	5.9
IVU	8.65	-	-	-	10.66	-	-	-
MCUG	10.17	39	-	-	7.77	-	-	-

Note: The studies in the table used either radiography (film screen/DR) or fluoroscopy (Conventional/digital)



R = Radiography, F = Fluoroscopy

Figure 4. Comparison of the kVp and mAs with other authors

In conclusion, the estimated lifetime cancer risk for BE, BS and IVU was compared to the HPA report [35]. The results shows that there was no statistically significant difference between both risk (P = 0.4431). The highest compared risk was for BE.

Table 6. Estimated lifetime cancer risk between this study and UK-HPA report

Procedure	Mean age (Years)	This study (per million)	HPA-UK (Per million) [35]
BE	44	223	101
BS	54	46	49
IVU	43	114	95

4. DISCUSSION

A study to determine the mean ESD, DAP and effective doses (E_{ff}) from radiographic interventional procedure have been carried out. The DR unit test were in line with studies from Ijabor et *al* [42] and Omojola et *al* [43]. Barium enema (BE), happens to have the highest ESD, DAP and E_{ff} compared to other procedures, while barium swallow (BS) had the least ESD, DAP and E_{ff}. The mean DAP for barium enema (BE) and barium swallow (BS) was the lowest compared to the UK [35], Ireland [36] and Japan [37] reports, while barium meal (BM) was lowest compared to the UK and Ireland reports. IVU in this study was similarly lower compared to the UK report. HSG and MCUG were higher compared to the UK report. The above results indicates that most of the protocols used could be sustained, since they were below diagnostic reference levels (DRL) from standard reports.

The above comparison were with fluoroscopy units and this is a vital point to notes that the radiographic interventional procedures can still achieve doses comparable to fluoroscopy systems, if optimization process are implemented.

This study from a Pearson correlation shows that there was association between ESD and DAP ($P < 0.001$), ESD and E_{ff} ($P = 0.007$) and DAP and E_{ff} ($P = 0.012$) for the 6 contrast-enhanced studies. Also, a One-Way Anova shows that ESD was affected by FFD ($P < 0.001$), field size ($P < 0.001$) and kVp ($P = 0.033$). This is because these factors are greatly controlled by the radiographer carrying out the exposures. This is why radiographic charts are often used to limit how kV and mAs parameters are used, with the aim of reducing patient dose and at the same time achieving diagnostic images.

The mean ESD from radiography contrast-enhanced study by Iacob et *al* with TLD-100 attached to patient skin for BE (83 mGy), HSG (57.4 mGy) and BM (55.2 mGy) exams was 7 times higher compared to this study, which used similar approach to estimate ESD. The E_{ff} doses were higher compared to this study. The study has used large amount of patient as this may contribute to the large mean doses being obtained [13].

The ESD from a study by Pataramontree et *al*, who used a fluoroscopy unit for BE (77.42 mGy) and BM (59.83 mGy) was 7 times higher compared to this study, however the IVU exam was comparable with this study with radiography [14]. Indicating that equipment type (conventional fluoroscopy systems/film screen radiography) and operator knowledge may greatly contribute to patient doses in the above study. This study has also acknowledged the fact that better understanding about protocol optimization has improved over the years globally and this may have reduced patient dose in this current study.

The entrance skin dose (ESD) was higher for this study compared to Zira et *al* [38] where the study was conducted in 2 facilities in the Northern part of Nigeria. The same similar trend was noticed for the DAP measurements except for BE and IVU procedures, which were lower compared to this study. However, fluoroscopy procedures from Wambani et *al* [10] was lower compared to this study except for BM, which higher than this study. Wambani's study has stated the use of additional copper filters, which is a key factor in absorbing low energy X-rays and invariably reducing patient dose.

The average kVp for this study was 77kVp, which was like Zira et *al*, while the average quantity ($Q = it$) in this study was 28 mAs, compared to Zira et *al*, which was 35 mAs. It was expected that the ESDs should be comparable between both studies but other factors like the focus to skin distance (FSD), the field size and the sensitivity of the TLDs used may have affected the dose outputs. On the other hand, Wambani et *al* used higher kVp compared to this study but with an average mAs of 9. The estimated cancer risk was compared to the United Kingdom (UK) Health Protection Agency (HPA) - CRCE-028 report [35]. The document has categorized various procedures into different band risk. The approximate estimated cancer risk for BE (1 in 4,500), BS (1 in 22,000) and IVU (1 in 9,000) were within the HPA recommended guidelines, which stipulate that the risk should be with 1in 1,000 to 1 in 10,000. Also, the BS fell within the “very low risk band”, while the BE and IVU fell within the “low risk band”. Indicating that the protocols can be sustained, since the risk are within limits.

5. CONCLUSIONS

A study to determine patient dose for contrast-enhanced X-Ray procedures was investigated using a medical facility's DR unit. ESD and DAP estimates were below most reported studies. The study showed that even countries conducting these studies with radiography can achieve doses comparable to standard fluoroscopic units. Optimization of HSG and MCUG procedures is still needed. This study is a preliminary investigation to involve other regional agencies in developing regional diagnostic reference levels in the future.

References

[1] Pomara C, Pascale N, Maglietta F, Neri M, Riezzo I, Turillazzi E. Use of contrast media in diagnostic imaging: medico-legal considerations. *Radiol Med.* 2015; 120 (9): 802-9

[2] Andreucci M, Solomon R, Tasanarong A. Side effects of radiographic contrast media: pathogenesis, risk factors, and prevention. *Biomed Res Int.* 2014; 2014: 741018

[3] Sun J, Li Z. Study on the Correlation between Barium Radiography and Pulmonary Infection rate in the Evaluation of Swallowing Function. *Clinics* 2018; 73: e182

[4] Wong VK, Ganeshan D, Jensen CT, Devine CE. Imaging and Management of Bladder Cancer. *Cancers* 2021; 13(6): 1396

[5] Schankath AC, Fasching N, Urech-Ruh C, Hohl MK, Kubik-Huch RA. Hysterosalpingography in the workup of female infertility: indications, technique and diagnostic findings. Insights Imaging. 2012; 3(5):475-83.

[6] Sulieman A, Elzaki M, Kappas C, Theodorou K. Radiation dose measurement in gastrointestinal studies. *Radiat Prot Dosimetry.* 2011; 147(1-2): 118-21

[7] Kasprzyk L, Chmaj-Wierzchowska K, Jurczyk MU. Physical parameters affecting the distribution of X-ray dose during hysterosalpingography. *Clin. Exp. Obstet. Gynecol.* 2020, 47(5), 729–735

[8] Mahajan A, Desai S, Sable NP, Thakur MH. Status of barium studies in the present era of oncology: Are they a history? *Indian J Med Paediatr Oncol.* 2016; 37(4): 223-226

[9] Faizah M, Kanaheswari Y, Thambidorai C, Zulfiqar M. Echocontrast cystosonography versus micturating cystourethrography in the detection of vesicoureteric reflux. *Biomed Imaging Interv J.* 2011; 7(1): e7

[10] Wambani JS, Korir GK, Tries MA, Korir IK, Sakwa JM. Patient radiation exposure during general fluoroscopy examinations. *J Appl Clin Med Phys.* 2014; 15(2), 262-270

[11] Buls N, Osteaux M. Patient and staff dose during hysterosalpinography. IAEA Publications. 2001: IAEA-CN-85-73

[12] Bonilha HS, Huda W, Wilmskoetter J, Martin-Harris B, Tipnis SV. Radiation Risks to Adult Patients Undergoing Modified Barium Swallow Studies. *Dysphagia.* 2019; 34(6): 922-929

[13] Iacob O, Diaconescu C. Doses to patients from diagnostic radiology in Romania. IAEA Publications. 2001; IAEA-CN-85-105: 53-57

[14] Pataramontree J, Wangsuphachart S. Patient and fetal dose in diagnostic and radiotherapy in Bangkok, Thailand. IAEA Publications. 2001; IAEA-CN-85-26: 527-531

[15] Milu C, Dumitrescu A, Marin R, Popescu FS. Radiation doses to patient in diagnostic radiology in Romania; comparison with guidance level and possibility of reduction. IAEA Publications. 2001; IAEA-CN-85-5: 17-20

[16] Spoelstra FM, Geleijns J, Broerse JJ, Teeuwisse WM, Zweers D. Patient dose surveys for radiological examinations in Dutch Hospital between 1993-2000. IAEA Publications. 2001; IAEA-CN-85-217: 79-83

[17] Einarsson G, Magnusson SM. Patient doses and examination frequency for diagnostic radiology in Iceland 1993-1998. IAEA Publications. 2001; IAEA-CN-85-263: 84-88

[18] Axelsson B. Optimisation in fluoroscopy. *Biomed Imaging Interv J.* 2007; 3(2): e47

[19] Crowhurst J, Whitby M. Lowering fluoroscopy pulse rates to reduce radiation dose during cardiac procedures. *J Med Radiat Sci.* 2018; 65(4): 247-249

[20] Kolck J, Ziegeler K, Walter-Rittel T, Hermann KGA, Hamm B, Beck A. Clinical utility of postprocessed low-dose radiographs in skeletal imaging. *Br J Radiol.* 2022; 95(1130): 20210881

[21] Idowu BM, Okedere TA. Diagnostic radiology in Nigeria: A country report. *J Glob Radiol.* 2020; 6(1): 1072

[22] Ekpo EU, Egbe NO, Azogor WE, Inyang SO, Upeh ER. Challenges of radiological equipment management policies in some northern Nigerian hospitals. *SAR.* 2013; 51: 19-22

[23] Sharma R, Sharma SD, Pawar S, Chaubey A, Kantharia S, Babu DA. Radiation dose to patients from X-ray radiographic examinations using computed radiography imaging system. *J Med Phys.* 2015; 40(1): 29-37

[24] Peacock NE, Steward AL, Riley PJ. An evaluation of the effect of tube potential on clinical image quality using direct digital detectors for pelvis and lumbar spine radiographs. *J Med Radiat Sci.* 2020;67(4): 260-268

[25] International Atomic Energy Agency (IAEA). Patient dose optimization in fluoroscopically guided interventional procedures. Vienna: IAEA; 2010. IAEA-TECDOC-164

[26] International Atomic Energy Agency, Dosimetry in diagnostic radiology: an international code of practice. Vienna: IAEA; 2007. Technical Reports Series No.: 457.

[27] Han SC. Preliminary study for dose evaluation depending on dose range with optically stimulated luminescence dosimeter considering individual dosimeter sensitivity. *PLoS One.* 2022; 17(3): e0266110

[28] Omojola AD, Adeneye SO, Akpochafor MO, Akala IO, Agboje AA. Comparison of entrance surface air kerma measurement with MTS-N (LiF: Mg, Ti) chips with a kilovoltage X-ray source. *ASEAN J Radiol.* 2021; 22(1): 20-34

[29] Omojola AD, Akpochafor MO, Adeneye SO, Aweda MA. Calibration of MTS-N (LiF: Mg, Ti) chips using cesium-137 source at low doses for personnel dosimetry in diagnostic radiology. *Radiat Prot Environ* 2020; 43: 108-14

[30] Yakoumakis E, Tsalafoutas IA, Nikolaou D, Nazos I, Koulentianos E, Proukakis C. Differences in effective dose estimation from dose-area product and entrance surface dose measurements in intravenous urography. *Br J Radiol.* 2001; 74(884): 727-34

[31] Hart D, Wall BF. Radiation exposure of the UK population from medical and dental X-ray examinations. NRPB-W4. Didcot: Chilton; 2002.

[32] Meiboom MF, Hoffmann W, Weitmann K, von Boetticher H. Tables for effective dose assessment from diagnostic radiology (period 1946–1995) in epidemiologic studies. *PLoS ONE.* 2021; 16(4): e0248987

[33] American Association of Physicists in Medicine (AAPM). Quality control in diagnostic radiology. AAPM report no. 74. American Association of Physicists in Medicine 2002.

[34] Institute of Physics and Engineering in Medicine (IPEM). Recommended standard for the routine performance testing of diagnostic X-ray imaging systems. York: IPEM; 2005.

[35] Hart D, Hillier MC, Shirmpton PC. Doses to patients from radiographic and fluoroscopic X-ray imaging procedure in the UK-2010 report. Didcot: Chilton; 2012. (HPA-CRCE-034). Adopted 2016

[36] Health Information and Quality Authority (HIQA). Diagnostic Reference Levels: Guidance on the establishment, use and review of diagnostic reference levels for medical exposure to ionising radiation. Dublin: HIQA; 2021.

[37] National Diagnostic Reference Levels in Japan (NDRLJ). Japan Network for Research and Information on Medical Exposure (J-RIME). 2020

[38] Zira JD, Nzotta CC, Skam JD. Diagnostic reference levels (DRLs) for contrast radiography examinations in North Eastern Nigeria. *PJR.* 2018; 28(1): 9-16

[39] Delichas MG, Hatziioannou K, Papanastassiou E, Albanopoulou P, Chatzi E, Sioundas A, Psarrakos K. Radiation doses to patients undergoing barium meal and barium enema examinations. *Radiat Prot Dosim.* 2004; 109(3), 243–247

[40] Nazlea BP. Determination of effective dose and entrance skin dose from dose area product values for barium studies in adult patients at a large tertiary hospital in the

Western Cape. Cape Peninsula University of Technology. South Africa. Published dissertation/thesis. 2017

[41] Ramsdale ML, Peet D, Hollaway P, Rust A. Patient dose surveys and use of local and national diagnostic reference levels. IAEA Publications. 2001; IAEA-CN-85-248: 434-439.

[42] Ijabor BO, Nzottza CC, Omojola AD. Quality control test of conventional X-Ray systems in Delta State, South-South, Nigeria. *World Scientific News* 157 (2021) 140-153

[43] Omojola AD, Akpochafor MO, Adeneye SO, Akala IO, Agboje AA. Chest X-rays of newborns in a medical facility: variation between the entrance skin dose measurements using the indirect and direct methods for clinical dose audit. *Jpn J Radiol* 40, 219–225 (2022)