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ESTABLISHMENT OF LOCAL DIAGNOSTIC REFERENCE LEVELS FOR CONVENTIONAL RADIOGRAPHY IN DELTA STATE, NIGERIA: A MULTI-CENTRE DOSE ASSESSMENT STUDY

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Abstract

Diagnostic Reference Levels (DRLs) are for optimizing radiation protection. However, data from low- and middle-income countries are under-represented with no current DRLs for conventional radiography in Nigeria, to establish local multi-centre DRLs for common radiographic examinations in Delta State, Nigeria, a study in three government hospitals (761 adults, mean age 45.4±18.0 years) measured Entrance skin dose (ESD), Kerma-area product (KAP), and absorbed dose to the abdomen, chest, lumbosacral spine, pelvis and skull using a calibrated Unfor Multi-O-Meter 710L. Quality control (QC) tests were done following the IAEA protocols. The DRLs were set at the 75th percentile of the ESD distributions. All QC parameters were within the international limits. The mean ESD was significantly different between facilities (1.49–2.65 mGy). Proposed DRLs (75th percentile) are: abdomen 3.08 mGy, chest PA 0.53 mGy, lumbosacral spine 4.09 mGy, pelvis 3.99 mGy and skull 2.06 mGy which is much lower than the IAEA guidance levels (e.g., 10.0 mGy for the abdomen/pelvis). ESD correlated highly with mAs (r=0.878).These preliminary DRLs for Delta State represent evidence-based benchmarks below international levels. Even though QC was acceptable, the large inter-facility dose variation underscores the urgent need for protocol standardization and ongoing staff training in dose optimization, not just equipment compliance.

Keywords: Diagnostic reference levels; radiation dose; entrance skin dose; dose optimization; ALARA

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1 Introduction

The main anthropogenic source of exposure for the world population is ionizing radiation from medical diagnostic procedures (Chen, 2024; UNSCEAR, 2021). It is estimated that between 2009 and 2018, 4.2 billion medical radiological exams were performed worldwide with an effective dose of 0.57 mSv per capita annually (UNSCEAR, 2021). In many high-income countries, the per-caput dose from medical procedures now equals or exceeds that from natural background sources (Chen, 2024). The fast growth of computed tomography and interventional radiology has maintained this trend and medical exposure is now the main source of man-made radiation for the population (Agbajor *et al,* 2022a; Agbajor *et al,* 2022b; Picone et al., 2025).

The International Commission on Radiological Protection (ICRP) has recommended Diagnostic Reference Levels (DRLs) as a useful optimization tool. Detailed recommendations can be found in ICRP Publication 135 (ICRP, 2017). DRLs are levels of investigation are typically set at the 75th percentile of the dose distribution of patients of standard size. If these levels are frequently exceeded, local review should be necessary (Nwabuoku *et al,* , 2026; Ukokeno *et al,* , 2024; Agbajor *et al,* 2025; Paulo et al., 2020). Since the inception of national DRLs, a number of countries have adopted or updated national DRLs for various imaging modalities. Recently, based on the latest national surveys, Sina et al. (2025) published Iran national DRLs for general radiography, interventional radiology, mammography and CT. Kim et al. (2025) revised the Korean national DRLs to include SiPM-based PET/CT scanners and new radiopharmaceuticals. The procedure for

developing the Japan DRLs was reported by Kanda et al. (2021). Khelassi-Toutaoui et al. (2020) have updated the Algerian adult CT DRLs. Masoomi et al. (2021) established the first national DRLs for hybrid PET/CT imaging in the State of Kuwait. Also, new studies support indication-adapted DRLs for dose reduction while preserving picture quality (Tsapaki et al., 2021; Osiga-Aibangbee *et al,*, 2024; Paulo et al., 2020; Picone et al., 2025 Osiga-Aibangbee *et al,* 2025).

While widely adopted in high-income countries, a critical gap remains in low- and middle-income countries (LMICs). Vassilevaand Rehani (2015) found that only about 80 out of 195 countries have national DRLs, predominantly high-income economies. As noted by Meyer et al. (2017) and supported by Adekanmi et al. (2025) in their systematic review protocol of African DRLs, LMICs, which house over 85% of the world's population, are heavily under-represented in DRL literature. This gap is more concerning when factoring in the particular challenges of LMICs, such as aging imaging equipment with inherent variability, less frequent quality control testing, limited access to dosimetry services, and a dearth of trained medical physicists (Adekanmi et al., 2025).

Nigeria, which is Africa's most populous nation with more than 200 million people, generates hundreds of thousands of radiographs annually. However, the available information on doses is grossly inadequate (Jibiri and Olowookere, 2016). A survey carried out in eight Nigerian states revealed that 9.1% of the hospitals never used dose monitoring devices and 81.8% never calculated patient doses as required by international standards (Oluwafisoye et al., 2010). Recent studies confirm this enduring gap. Kabeer et al. (2024) established local CT DRLs in Sokoto State and concluded that extensive nationwide dose surveys are required in Nigeria to establish national reference doses. Samaila and Bello (2024) revealed that entrance skin doses in Kebbi State were higher compared to international reference doses for abdominal X-ray examinations. Adeyemi (2025) observed significant differences in dose descriptors for radiological procedures in Ondo State, thus corroborating the need for standard national protocols. This contributed to the growing but still fragmented national dose database. Muhammad et al. (2025) estimated patient skin entrance and effective doses for diagnostic X-ray examinations in Niger State. Nworgu and Bamidele (2025) examined entrance and surface doses at two teaching hospitals in Nigeria, contributing to the growing body of evidence on inter-facility variability. Saad et al. (2024) specifically focused on dose optimization and radiation safety for paediatric patients in the North Eastern Nigeria, identifying a vulnerable population requiring urgent attention.

An early survey in Delta State indicated that dose charts were used in only 57% of the X-ray centres (Anomonharan et al., 2002). However, with the spread of X-ray facilities in the intervening two decades, no comprehensive dose assessment has been done, although the state has approximately 45 registered X-ray facilities with a population of 5.6 million people.

The novelty of this study is to provide the first systematic, multi-centre dose data and local DRLs for Delta State using contemporary equipment and validated dosimetry protocols. This addresses a key regulatory need of the Nigerian Nuclear Regulatory Authority (NNRA) and provides an evidence-based benchmark, rather than adopting potentially inappropriate international values. Thus, the aim of this study was to establish local DRLs for adult conventional radiographic examinations in Delta State government hospitals.

2. Materials and Methods

2.1. Study Design and Setting

The prospective cross-sectional study was conducted in the radiology departments of three government hospitals in Delta State, Nigeria namely Delta State University Teaching Hospital, Oghara (Facility X1), Central Hospital, Warri (Facility X2) and Asaba Specialist Hospital, Asaba (Facility X3) between June and November 2025. The facilities were deliberately chosen to reflect

variations in patient volumes, equipment age and geographic distribution across the three senatorial districts in the state.

2.2. Ethical Considerations
The Health Research and Ethics Committees of the three study centres approved the study with approval numbers DELSUTH/HREC/2025/042; CHW/ETH/2025/018 and ASH/ERC/2025/023. Written informed consent was obtained from all participants and alldata obtained were anonymised at the point of collection.

2.3. Study Population and Inclusion Criteria
Adult patients (≥18 years) who underwent routine radiographic examinations during the study period were consecutively included (n = 761). Inclusion criteria were: (1) body weight of 55-80 kg (standardized for patient habitus); (2) routine diagnostic examination without contrast media; (3) complete documentation of exposure parameters; and (4) willingness to give informed consent. Exclusion criteria included: (1) pregnancy; (2) previous radiation therapy to the imaged region; (3) presence of radiopaque implants; and (4) repeat examinations.

2.4. Equipment and Instrumentation
Facility X1 used an old KEHRLI RONTGEN unit (Switzerland, 1984). Facilities X2 and X3, used newer Canon Electron Tubes E7239X units (Japan, installed 2020 and 2023 respectively). The radiation measurements were performed using a calibrated Unfor Multi-O-Meter 710L (Unfors Instruments AB, Billdal, Sweden) solid state detector system for simultaneous measurement of the kVp, dose (mGy), dose rate, exposure time and tube current (energy range 40-150 kVp, accuracy ±5%).

Phantom Justification:A polystyrene water-equivalent phantom (30×30×20 cm) was used for all dose measurements to simulate the attenuation of the patient. This method allowed the reproducible patient-independent dose determination for given exposure parameters, which is an important step for establishing standardized DRLs by eliminating the anatomical variability between patients (IAEA, 2018).

2.5. Quality Control Procedures
All quality control tests were performed under consistent ambient conditions (25-28°C, 50-70% relative humidity) after warm-up of the tube, following protocols of IAEA (2018) and AAPM (1991). Dose reproducibility, coefficient of variation (COV) and exposure linearity were assessed. Acceptance criteria were defined as ± 5% of international limits for all parameters.

2.6. Patient Radiation Dose Determination
The water phantom was irradiated using the recorded parameters (kVp, mAs, FFD, FSD, beam size) for each clinical examination. The ESD (mGy) was directly read from the dosimeter on the surface of the phantom. KAP (mGy·cm^2) was calculated as KAP = ESD × beam area (Chen et al., 2020; IAEA, 2018). The detector under the phantom was used to determine the exit dose and the absorbed dose (D) was calculated as D = ESD - ED.

2.7. Diagnostic Reference Level Determination
DRLs were set at the third quartile (75th percentile) of the distribution of ESDs for each examination type based on the ICRP (2017) guidance, which is the value below which 75% of measured doses are found.

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2.8. Statistical Analysis

Data analysis was performed using Python 3.11 on the ANACONDA platform (Anaconda Inc., Austin, TX, USA). Descriptive statistics (mean, standard deviation, median, percentiles, and range) were calculated for all continuous variables. Pearson correlation coefficients (r) were calculated for relationships between ESD and potential predictors: kVp, mAs, kVp × mAs product, KAP, FFD, FSD, FFD/FSD ratio, beam dimensions, and patient age.

Encoding Justification: To enable statistical modelling, categorical variables (facility, examination type, sex) were numerically encoded using integer codes (e.g., X1=0, X2=1, X3=2; Abdomen=0, Chest=1, etc.) after confirming no ordinal relationship existed between categories. This is a standard practice for handling nominal data in linear and logistic regression analyses.

Mean ESD between facilities and examination types were compared by one-way analysis of variance (ANOVA) and post-hoc Tukey HSD test. Statistical significance was set at $\alpha = 0.05$.

3. Results

3.1. Quality Control Performance

The three facilities met the IAEA (2018) acceptance criteria as shown in Table 1 and Figure 1. The reproducibility value was 3.79% for facility X1, 2.41% for X2, and 0.30% (significantly lower) for X3. The COV values for X1, X2 and X3 were 3.13, 1.92 and 0.30%, respectively. The deviations of the linearity of the exposure were 3.74% (X1), 2.40% (X2) and 0.25% (X3). All the values were well within the internationally accepted tolerance limit of ±5%, indicating stable and consistent X-ray output from all the machines. The better performance of facility X3 indicates the benefits of newer equipment and good quality assurance measures.

Table 1: Quality Control Test Results across Facilities

Parameter	Facility X1	Facility X2	Facility X3	Acceptance Criterion
Dose reproducibility (%)	3.79	2.41	0.30	≤5%
Coefficient of variation (%)	3.13	1.92	0.30	≤5%
Exposure linearity (%)	3.74	2.40	0.25	≤5%

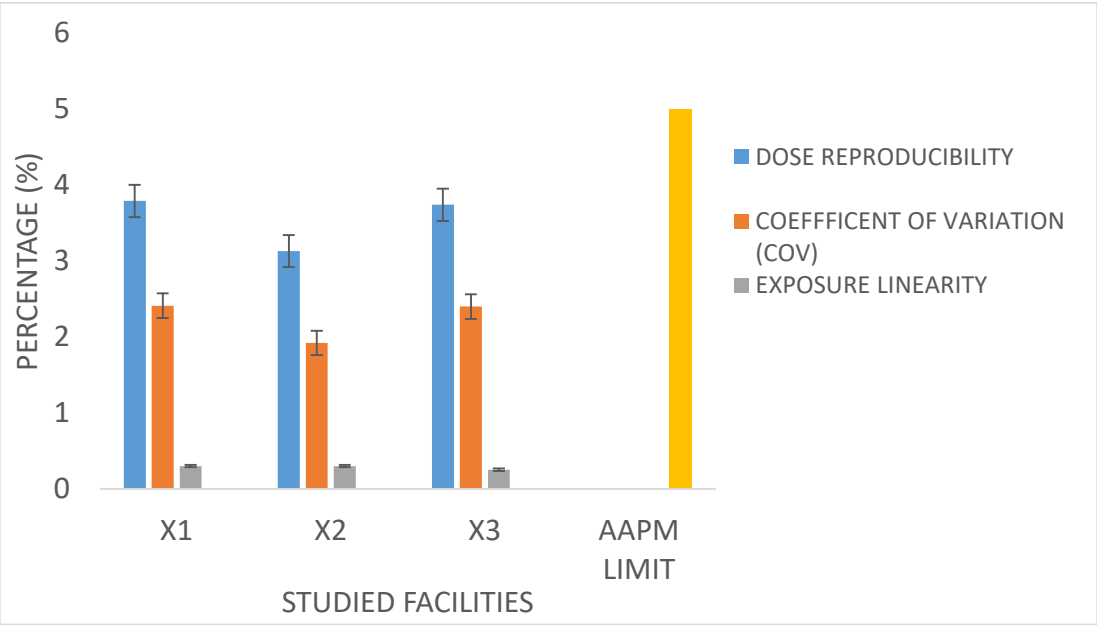

Figure 1: Quality Control Performance vs. International Limits

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3.2. Patient Demographic and Exposure Characteristics

A total of 761 patients (48.5% male, 51.5% female) with a mean age of 45.4 years (range 18-95; SD 18.0) were included as shown in Table 2. Median exposure parameters were: kVp 75.0 (range 50-99), mAs 25.0 (5-80), FFD 120 cm (100-180), FSD 92.5 cm (68-170), and beam area 1071.5 cm^2 (428-1445).

Table 2: Descriptive Statistics of Exposure and Patient Parameters

Parameter	Mean ± SD	Median	Range	25^{th}-75^{th} %ile
kVp	72.3 ± 9.4	75.0	50-99	65.0-80.0
mAs	29.5 ± 14.5	25.0	5-80	15.8-45.0
FFD (cm)	127.2 ± 24.7	120	100-180	100-150
FSD (cm)	99.6 ± 26.4	92.5	68-170	78.2–125.5
Beam area (cm^2)	1028.6 ± 206.8	1071.5	428-1445	908.8-1167.4
Age (years)	45.4 ± 18.0	44.0	18-95	29.0-59.0

3.3. Patient Radiation Doses by Examination Type

Table 3 presents the ESD, KAP and absorbed dose values for the five examination types. One-way ANOVA showed that there were significant differences in mean ESD among the types of examination ($F = 287.4$, $p < 0.001$). The mean ESD was highest for lumbosacral spine examinations (3.73 ± 1.08 mGy), which was about nine times higher than chest examinations (0.42 ± 0.38 mGy) due to higher mAs requirements and increased tissue attenuation.

Table 3: Patient Radiation Doses by Examination Type

Examination	n	ESD (mGy) Mean ± SD	ESD Median	KAP (mGy·cm^2) Mean ± SD	Absorbed Dose (mGy) Mean ± SD
Abdomen	82	2.22 ± 1.33	1.89	2481.5 ± 1158.2	2.21 ± 1.33
Chest	300	0.42 ± 0.38	0.30	498.6 ± 540.2	0.42 ± 0.38
Lumbosacral	226	3.73 ± 1.08	3.75	3529.5 ± 1645.8	3.72 ± 1.08
Pelvis	95	2.94 ± 1.38	2.71	3322.8 ± 1825.4	2.93 ± 1.38
Skull	58	1.83 ± 1.01	1.43	1072.1 ± 492.3	1.82 ± 1.00
Overall	761	2.02 ± 1.70	1.60	2000.4 ± 1817.5	2.01 ± 1.70

3.4. Facility-wise Dose Distribution

Despite the similarities in patient population in government hospitals, there are differences in average ESDs in all government hospitals (Table 4 and Figure 2). ANOVA showed significant differences between facilities ($F = 34.2$, $p < 0.001$). The highest mean ESD was found at facility X3 (2.65 mGy) and the lowest at X2 (1.49mGy) with a difference of 78% ($p<0.001$, Tukey HSD). Differences were noted in all exam types, suggesting systematic variations in radiographic protocol and technique selection, not random variation.

Table 4: Facility-wise Comparison of Entrance Skin Dose

Facility	n	Mean ESD (mGy)	Median ESD (mGy)	SD	Range	75th %ile
X1	241	1.80	1.28	1.60	0.24-5.07	2.58
X2	236	1.49	0.85	1.29	0.06-4.23	2.14
X3	284	2.65	2.15	1.89	0.31-8.33	3.89
Total	761	2.02	1.60	1.70	0.06-8.33	3.08

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Figure 2: Facility-wise Comparison of Entrance Skin Dose Distributions

3.5. Proposed Local Diagnostic Reference Levels

Table 5 Proposed local DRLs (75th percentile of ESD) for Delta State compared with international reference values. The proposed DRLs for abdominal, pelvic and lumbosacral examinations (3.08-4.09 mGy) are approximately 60-70% lower than the IAEA (1996) guidance levels of 10.0 mGy. The PA chest DRL (0.53 mGy) is slightly higher than the UK (0.30 mGy) and IAEA (0.40 mGy) values, but within operational ranges reported from other LMICs. These differences are summarized in a comparative bar chart (Figure 3).

Table 5: Proposed Delta State DRLs Compared with International Standards (ESD, mGy)

Examination	This Study (75th %ile)	UK (NRPB 1999)	IAEA (1996)	European Commission (1999)	USA (AAPM 1999)
Abdomen (AP)	3.08	10.6	10.0	10.0	4.50
Chest (PA)	0.53	0.30	0.40	0.30	0.25
Lumbosacral spine (AP)	4.09	10.5	10.0	10.0	5.00
Pelvis (AP)	3.99	10.4	10.0	10.0	-
Skull (AP/PA)	2.06	5.00	5.00	5.00	-

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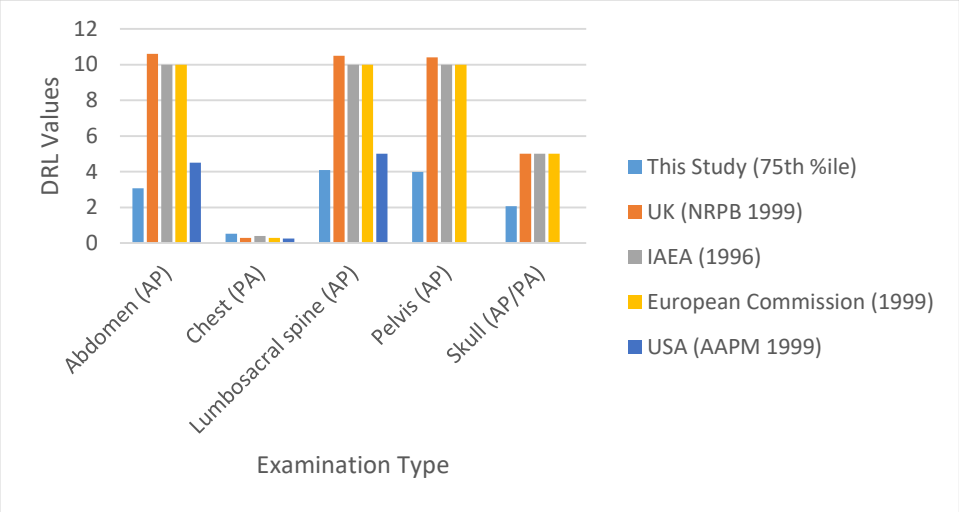

Figure 3: Comparison of Proposed Delta State DRLs with International Standards

3.6. Correlation Analysis

Table 6 shows Pearson correlation coefficients between ESD and selected parameters. The full correlation matrix heatmap is shown in Figure 4. KAP is the product of beam intensity and field area. Therefore, the strong correlation between ESD and KAP (r = 0.963) is not unexpected. The correlations of mAs (r = 0.878) and kVp (r = 0.702) confirm that mAs is the dominant determinant of dose as expected from basic X-ray physics. Moderate inverse correlations of ESD with FFD (r = −0.425) and FSD (r = −0.464) support the practical significance of the inverse square law.

Table 6: Pearson Correlation Coefficients between ESD and Selected Parameters

Parameter	Correlation (r)	95% CI	p-value	Strength
KAP (mGy·cm²)	0.963	0.958-0.968	<0.001	Very strong (+)
kVp × mAs product	0.945	0.937-0.952	<0.001	Very strong (+)
MAs	0.878	0.863-0.892	<0.001	Strong (+)
kVp	0.702	0.667-0.734	<0.001	Moderate-strong (+)
FFD/FSD ratio	0.466	0.416-0.513	<0.001	Moderate (+)
FFD (cm)	-0.425	-0.475- -0.373	<0.001	Moderate (-)
FSD (cm)	-0.464	-0.511- -0.414	<0.001	Moderate (-)
Beam area (cm²)	-0.225	-0.289- -0.159	<0.001	Weak (-)
Age (years)	0.268	0.203-0.331	<0.001	Weak (+)
Sex (encoded)	0.018	-0.063-0.099	0.662	Negligible

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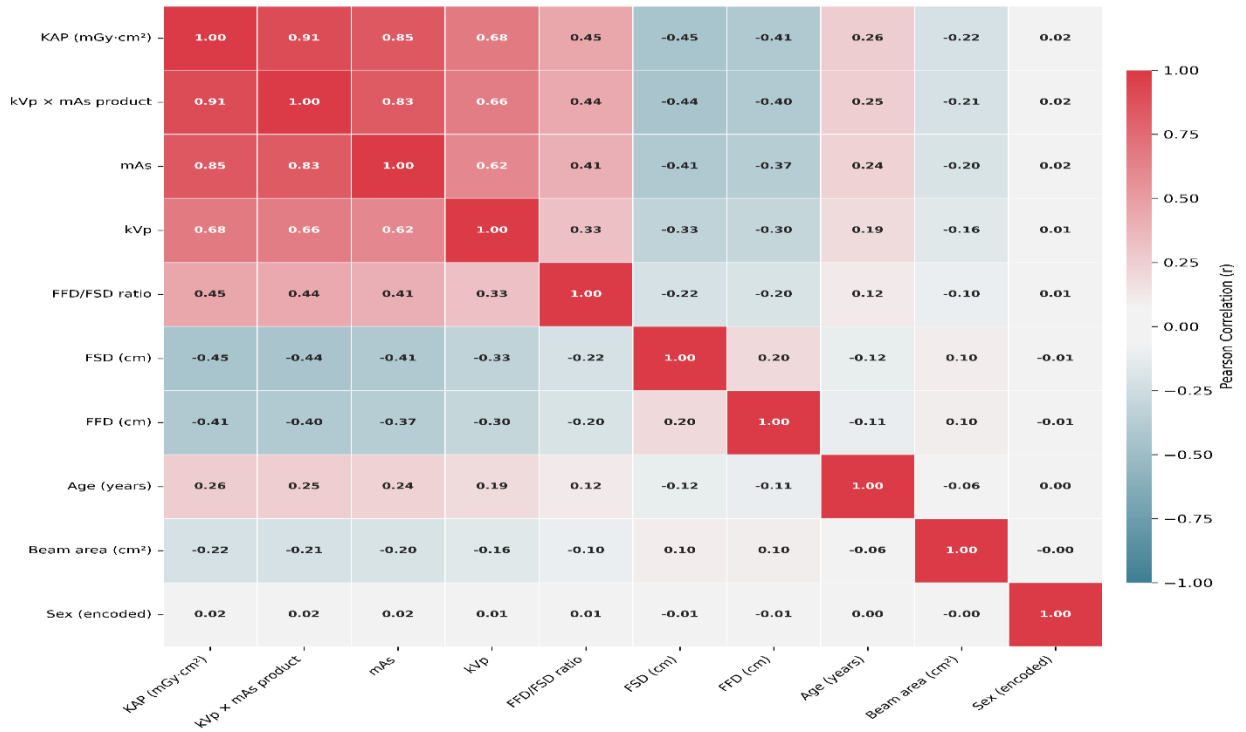

Figure 4: Correlation Matrix of Radiation Exposure Parameters

4. Discussion

This study established the first local Diagnostic Reference Levels for conventional radiography in Delta State, Nigeria. Three main findings were obtained: (1) Equipment quality control was within the international limits for all facilities, but large inter-facility dose variation was observed (78% difference in mean ESD); (2) The proposed DRLs for abdomen, pelvis and lumbosacral spine (3.08-4.09 mGy) were significantly lower than IAEA guidance values of 10.0 mGy; (3) Correlation analysis confirmed mAs as the dominant dose determinant (r = 0.878).

The Paradox of Dose Variation and Quality Control: The three facilities met IAEA (2018) QC acceptance criteria, with reproducibility values (0.30–3.79%) and COV values (0.30–3.13%) well below the 5% tolerance limit. However, mean ESD differed by a factor of 1.78 across facilities. The paradox of acceptable equipment performance with large dose variation indicates that major dose drivers are not equipment malfunction but operator-dependent factors such as protocol selection, technique chart adherence, collimation practices, and positioning. This is in agreement with findings of Edet & Okon (2015) that human factors are key contributors to patient dose escalation in Nigerian diagnostic radiology and Muhogora et al. (2008) who reported 2 to 5 folds dose variations between African facilities even with acceptable QC.

Comparison with International and Nigerian DRLs: Our DRLs for abdominal, pelvic and lumbosacral examinations are about 60-70% lower than the guidance levels of IAEA (1996). This is different from some previous Nigerian studies. LDRLs of 2.71-2.84 mGy for abdomen and 3.93-8.79 mGy for lumbosacral spine were reported by Jibiri&Olowookere (2016) in southwest Nigeria. Osahon & Bamidele (2017) reported mean ESD values for pelvis (2.84 mGy) and lumbosacral (4.96 mGy) which were generally higher than our medians. Our chest DRL of 0.53 mGy is in line with values reported in Ethiopian hospitals (Tsegaye, 2024) and Nigerian studies from the North-East (Joseph

et al., 2017; Muhammad et al., 2025) but still exceeds UK and IAEA values, indicating a specific optimization target: the implementation of 180 cm FFD for chest examinations could reduce ESD by approximately 30% without loss of image quality. Correlation analysis offers quantitative evidence to identify the factors that influence dose variation. A very strong correlation between ESD and KAP (r=0.963) and between ESD and mAs (r=0.878) confirms that tube loading is the dominant operator controlled factor. Moderate inverse correlations between ESD and FFD (r=-0.425) and FSD (r=-0.464) are consistent with the inverse square law. One of the most cost effective dose reduction strategies is to increase the source-to-skin distance from 100 cm to 120 cm, which can decrease the ESD by about 31%.

Clinical and Regulatory Implications for Nigerian Implementation: The findings have a number of implications for action:

For radiographers and radiology departments: The proposed DRLs should be used as local investigation levels. A protocol should be reviewed if any examination is consistently above the 75th percentile. Optimizations that could reduce the mean ESD by 20-40% without compromising image quality are use of higher kVp with lower mAs for chest radiography, increasing FFD where anatomically feasible and optimal collimation (ICRP, 2007; Sowa et al., 2025).

For hospital administrators: The 78% variation in dose between facilities is a safety gap that can be closed by investment in regular quality control testing (minimum quarterly) and retraining staff in dose optimization, as demonstrated in recent paediatric dose optimization studies (Saad et al., 2024; Kim et al., 2025).

Nigerian Nuclear Regulatory Authority (NNRA): It is advised to do this in a phased manner: (1) Immediate adoption of these DRLs as "investigation levels" for all government hospitals in Delta State; (2) Mandatory quarterly QC and protocol audits for facilities that consistently exceed the 75th percentile; (3) A nationwide multi-zone survey (covering the six geopolitical zones of Nigeria) to establish national DRLs stratified by equipment type (CR vs DR) and patient size categories, as recommended by Kabeer et al. (2024) and in line with recent national DRL updates in Iran (Sina et al., 2025) and Korea (Kim et al., 2025).

5. Conclusion

This study established the first local Diagnostic Reference Levels for conventional radiography in Delta State, Nigeria. The suggested DRLs are: abdomen 3.08 mGy, chest PA 0.53 mGy, lumbosacral spine 4.09 mGy, pelvis 3.99 mGy and skull 2.06 mGy. The IAEA guidance levels for abdomen and pelvis exams are substantially above these benchmarks, indicating effective dose optimization practices in the region despite resource constraints. The key finding is that although all facilities meet international QC acceptance criteria, there is still a 78% inter-facility dose variation. This is a demonstration that dose optimization is not achievable with equipment performance alone. The variation in patient dose is mainly due to operator-dependent factors such as protocol selection, technique chart adherence, collimation and positioning. This changes the optimization challenge: it is about active dose management and ongoing staff training, not passive equipment compliance.
Strong correlations were observed between ESD and exposure parameters (mAs: r = 0.878, kVp: r = 0.702), which can be used as a quantitative guideline for optimization. Facilities with mean doses higher than the proposed DRLs need an urgent review of their technique charts especially for mAs reduction wherever diagnostically possible and FFD/FSD ratio optimization. The NNRA should consider including DRL-based dose audits as a licensing requirement and support a comprehensive nationwide DRL survey across Nigeria's six geopolitical zones. These DRLs for specific regions are a

beginning, not an end. Regular review (every 3-5 years) will ensure that as technology and practice evolve these DRLs continue to protect patients from unnecessary radiation exposure while maintaining diagnostic benefits.

Limitations: The study has several limitations. First, patients with a body weight >80 kg were excluded for standardization but this limits generalizability. Secondly, only government hospitals were included, dose profiles may differ in private facilities. Third, image quality was not rated independently but routine acceptability was confirmed by clinical radiologists. Fourth, the sample size of the skull examination (n=58) was smaller than the other projections. Fifth, the Mult-O-Meter uses a phantom-based ESD estimation to estimate air kerma. Future validations with in vivo thermoluminescent dosimeter measurements would be useful.

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Declaration Statement
Conflict of Interest: The authors have no conflicts of interest, financial or otherwise, to declare.

Ethics Approval: Ethical approval was obtained from the Health Research and Ethics Committees of Central Hospital Warri (CHW/ETH/2025/018), DELSU Teaching Hospital Oghara (DELSUTH/HREC/2025/042) and Asaba Specialist Hospital (ASH/ERC/2025/023). All procedures were in accordance with the 1964 Declaration of Helsinki and later amendments.

Informed Consent: Written informed consent was obtained from all individual participants included in the study.

Data Availability: The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request subject to institutional data protection policies.

Authors' Contributions: E.O., A.F.A; A.G.K conceptualization; E.O., O.E methodology; Data curation: E.O; Formal analysis: E.O; Writing-original draft: E.O; Writing-review & editing: A.F.A, A.G.KO.E; Supervision: A.F.A, O.E. All authors have approved the final version.

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