INTER-CENTRE VARIABILITY IN EFFECTIVE RADIATION DOSE AND THE INFLUENCE OF SCAN PARAMETERS IN ROUTINE COMPUTED TOMOGRAPHY EXAMINATIONS: EVIDENCE FROM THREE DIAGNOSTIC CENTRES IN NORTHWESTERN NIGERIA

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Abstract – **Effective dose is broadly used to estimate the overall stochastic risk associated with computed tomography (CT) examinations and to support dose comparison between scanners/centres. There has been a steady increase in the installation and utilisation of medical imaging modality in Nigeria; however, CT dose monitoring and reporting have not received commensurate attention. This study aimed to compute effective dose values for routine head, chest, and abdominal CT examinations in Sokoto State, Nigeria; evaluate inter-centre variability; and investigate the influence of scan parameters on patient dose. A prospective study was conducted in three different Nigerian Nuclear Regulatory Authority accredited diagnostic centres using multi slice CT scanners. Data from 750 patients, aged 0-80, were collected, including demographic characteristics, scan parameters, and dose length product (DLP). Effective dose was estimated using region-specific conversion coefficients based on International Commission on Radiological Protection (ICRP) 103 recommendations. Inter-centre comparisons were performed, and regression analysis assessed the relationship between effective dose and scan parameters such as tube voltage, tube current, and scan length. This study found significant variation in effective dose between centres for the same CT examinations, reflecting differences in scanner technology, protocol settings, and optimisation practices. Regression analysis identified tube current and scan length as the most influential factors affecting effective dose, though their impact varied by centre. Some effective dose values exceeded international benchmarks, suggesting a need for optimisation. These results highlight the importance of standardised protocols and locally established diagnostic reference levels to improve dose consistency and patient safety in CT practice.**

Keywords – **Effective dose, computed tomography, inter-centre variability, scan parameters, radiation optimisation, Nigeria .**

I. INTRODUCTION

Computed Tomography (CT) is one of the most used diagnostic imaging techniques in modern medicine due to its diagnostic accuracy, speed, and expanding clinical indications (Mahesh, 2013; Maidamma et al., 2026; Yu et al., 2009). CT scans expose patients to ionizing radiation, a known human carcinogen. From 1997 through 2007, CT scans and nuclear medicine procedures became the largest source of exposure to ionizing radiation and accounted for 24% of the exposure in the US population (Maidamma et al., 2026; Sekkat et al., 2025; Shao et al., 2020). It is impractical to directly measure the radiation dose absorbed by individual patients even when the radiation emitted by a machine is precisely known. Instead, radiation exposure may be quantified using various methods, including effective dose (ED) (Smith-Bindman et al., 2009; Trotter et al., 2023; Uniyal et al., 2025). Effective dose is the measure of radiation calculated with the radiosensitivity of specific organs considered. It is measured in Sievert (Sv) (Maidamma et al., 2026; Maidamma & Samaila, 2024). ED was introduced by the International Commission on Radiological Protection (ICRP) for the needs of radiation protection and the assessment of radiation risks, expressed as health detriment due to stochastic effects (Avramova-Cholakova et al., 2022; Dendy & Heaton, 1999; Maidamma et al., 2026; Maidamma & Samaila, 2024; Uniyal et al., 2025; Wang et al., 2022). Although ED was not intended for individual patient risk estimation (Foley et al., 2012; Sekkat et al., 2025; Trotter et al., 2023; Uniyal et al., 2025), it remains an essential tool for body risk assessment, dose benchmarking, and the establishment of diagnostic reference levels (DRLs)(Maidamma & Samaila, 2024; Sekkat et al., 2025). Several studies have demonstrated substantial variations in effective dose for similar CT examinations performed at different centres, often attributable to differences in scan parameters, protocol selection, equipment performance, and operator practice (Einstein et al., 2007; Maidamma et al., 2026; Maidamma & Samaila, 2024). Such inter-centre variability indicates opportunities for optimization and highlights the need for locally generated dose data. In low- and middle-income countries, including Nigeria, data on patient radiation doses from CT examinations remain limited (Garba et al., 2021; Mahesh, 2013; Maidamma & Samaila, 2024), and national DRLs are either absent or based on sparse information. In Sokoto State, CT services are expanding, yet there is little published evidence evaluating effective dose levels across centres or examining whether current practices align with international recommendations (Garba et al., 2021; Mahesh, 2013; Maidamma, 2021). Without such data, it is difficult to assess patient radiation risk, compare local practice with global standards, or identify factors contributing to unnecessarily high doses.

Scan parameters such as tube voltage (kVp), tube current–time product (mAs), scan length, pitch, and the use of automatic exposure control have a direct and significant

influence on radiation dose in CT (Garba et al., 2021; ICRP, 2007; Maidamma et al., 2026). Quantifying the relationship between effective dose and these parameters using statistical methods, including regression analysis, provides valuable insight into the determinants of patient dose and supports evidence-based optimization strategies. This study aims to estimate the effective dose associated with head, chest, and abdominal CT examinations in selected centres in Sokoto State, evaluate inter-centre variability, and compare local dose levels with published literature. Furthermore, the study investigates the influence of key scan parameters on effective dose and employs regression analysis to determine the strength of these relationships.

Theoretical Background

CT scans often involve high radiation doses compared to other imaging procedures, thus monitoring and minimizing the effective dose is essential for optimizing patient safety and complying with international standards set by organizations like the ICRP (Brage et al., 2025; ICRP, 2007; Maidamma et al., 2026). Many scholars give their verdict on the importance of effective dose estimation especially in CT with use of non-ionization radiation that primarily rely on stochastic effect risk.

CT Effective Dose

In CT, the ED helps quantify the stochastic health effects such as cancer and genetic mutations resulting from ionizing radiation (Bąk et al., 2025; Brage et al., 2025; Kalra et al., 2004). Effective dose thus is not a dose metric for a specific individual (Kalra et al., 2004; Zanzonico, 2024). It represents a population-averaged risk estimate, derived from reference phantoms and epidemiological models (Almaasfeh et al., 2023; Arjmandi et al., 2024; Zanzonico, 2024). Recent studies increasingly caution against misuse of effective dose in clinical risk prediction, especially when researchers attempt to relate it directly to tissue-level effects, DNA damage (Albahiti et al., 2022; Almaasfeh et al., 2023; Greene-Schloesser et al., 2012). Effective dose is calculated using the dose-length product (DLP) and region-specific conversion coefficients (k-factors) as show in the equation (Chaparian, 2018; Maidamma et al., 2026).

$$ED = DLP \times k \quad (1)$$ (Maidamma et al., 2026)

Table 1: *k* – Value for CT scan (ICRP, 2007; Maidamma et al., 2026)

Body Region	Adult (≥ 16 Yrs)	Children (15-10 Yrs)	Children (9-2 Yrs)	Infant (1 Yrs)
Head	0.0021	0.0023	0.0042	0.0067
Chest	0.014	0.021	0.026	0.039
Abdomen	0.015	0.019	0.023	0.032

Head CT

Head CT examinations are routinely performed to evaluate intracranial pathologies such as trauma, stroke, haemorrhage, and tumours (ICRP, 2007; Kesmezacar et al., 2026; Maidamma et al., 2026). The procedure typically involves axial acquisition from the skull base to the vertex using relatively high tube current and moderate tube voltage to overcome the high attenuation of the skull bones and achieve adequate contrast resolution (Trotter, 2023; (Chaparian, 2018; Dendy & Heaton, 1999; Kesmezacar et al., 2026; Mahesh, 2013; Maidamma et al., 2026). Consequently, head CT contributes significantly to localised organ absorbed dose despite producing a comparatively lower effective dose than body CT examinations (ICRP, 2007; Maidamma et al., 2026). Dose optimisation strategies such as reduced tube current, appropriate scan length, and lens shielding are therefore critical in head CT imaging (Brage et al., 2025; ICRP, 2007).

Chest CT

Chest CT is widely used for the assessment of pulmonary diseases, mediastinal abnormalities, cardiac conditions, and oncological staging (Brage et al., 2025; Garba et al., 2021; Kesmezacar et al., 2026). Due to the relatively large scan volume and the inclusion of multiple radiosensitive organs, chest CT results in substantial organ absorbed doses, particularly to the lungs, breast, heart, thyroid, and bone marrow (Maidamma et al., 2026). Variations in patient body habitus, scan length, and tube current modulation further influence absorbed dose distribution (Kesmezacar et al., 2026). Optimisation in chest CT is therefore essential, with emphasis on protocol tailoring, automatic exposure control, and careful justification to minimise unnecessary radiation exposure (Barker et al., 2007; Kesmezacar et al., 2026; Maidamma et al., 2026; Sekkat et al., 2025).

Abdominal CT

Abdominal CT examinations are commonly performed to investigate hepatic, gastrointestinal, renal, and pelvic pathologies (Aboul Hamad et al., 2023; Mahesh, 2013; Sekkat et al., 2025). The procedure typically covers a long anatomical range and often employs higher tube current and longer scan times to maintain adequate image quality through soft tissues with varying densities (Aboul Hamad et al., 2023; Mahesh, 2013; Maidamma et al., 2026). Many of these organs have moderate to high tissue weighting factors, indicating a significant contribution to overall radiation risk (Maidamma et al., 2026). Careful optimisation of scan parameters, limitation of scan length, and justification of multiphase studies are essential to reduce unnecessary organ dose while maintaining diagnostic efficacy (ICRP, 2007; Kalender, 2011; Mahesh, 2013; Maidamma et al., 2026).

II. MATERIALS AND METHODS

Study Area

The study was conducted in Sokoto Metropolis, Sokoto State, located in northwestern Nigeria. The state shares borders with the Republic of Niger to the north and west, Zamfara State to the east, and Kebbi State to the south and west. It covers a land area of 28,232.37 square kilometers and lies within the savannah vegetation zone.

Study Population

Eligible participants included male and female patients aged 0–80 years scanned using multi-slice CT systems capable of displaying dose metrics on the console at Usmanu Danfodiyo University Teaching Hospital, Sokoto State advance Medical Diagnostic Centre and Caliphate clinical and Diagnostic Centre; while critically ill patients unable to stand on a floor weighing scale were excluded.

Ethical Consideration

Institutional ethical clearance was obtained from the Ethical Committees of the three participating centers: Usmanu Danfodiyo University Teaching Hospital (UDUTH/HREC/2024/1438/V2), Sokoto State advance Medical Diagnostic Centre (SSAMDC/HREC/2024/01), and Caliphate clinical and Diagnostic Centre (CCDC/HREC/2024/021), with patient consent obtained or waived in accordance with the approved protocols.

Sample size

A total of 900 adult and paediatric patients undergoing routine computed tomography examinations were prospectively recruited from three Nigerian Nuclear Regulatory Authority accredited diagnostic centres, with 300 patients sampled from each centre, in compliance with the European Commission guideline recommending a minimum of 10 patients per CT procedure (Garba et al., 2021; Maidamma et al., 2026).

Study Equipment and Data Collection

The study employed three multi-slice CT scanners of different technological generations a GE LightSpeed 4-slice unit installed in 2011, a Philips Brilliance 16-slice unit installed in 2019, and a GE Brivo-series 16-slice unit installed in 2021. Prior to scanning, patient demographic data such as age, sex, body weight, and height were collected, with weight measured using a calibrated floor scale and height using a measuring tape, while additional information was obtained from medical records or the radiology information system and recorded on a structured data collection form. For each examination, key scan parameters including tube voltage, tube current, and scan length were extracted directly from the scanner console, as these factors significantly influence radiation dose delivery.

Statistical Analysis

All collected data were analysed using Minitab statistical software, where descriptive statistics such as mean, range, standard deviation, and the 75th percentile were computed to characterise patient demographics, scan parameters, and radiation dose metrics and to facilitate inter-centre dose comparison and evaluation.

III. RESULTS

Effective Dose received by the Patients

Individual values of effective dose for all patients were calculated and the mean regional values for each centre were statistically derived (Table 1). The highest average dose was recorded for head CT examinations in Centre A at 3.65 mSv (±2.65), followed by Centre B at 2.31 mSv (±1.36), and Centre C at 1.14 mSv (±0.45). Chest CTs revealed mean doses of 1.68 mSv, 0.69 mSv, and 0.68 mSv in Centres A, B, and C respectively, while abdominal scans yielded relatively lower mean doses ranging from 0.69 mSv to 0.74 mSv across the three centres. These findings demonstrate a consistent pattern, head CT scans deliver the highest radiation doses, followed by chest and abdominal scans Table 4.0. This variation can be attributed to differences in scan protocols, anatomical density, and the length of scanned regions. Head CTs often involve higher tube currents and multiple sequences, resulting in greater exposure (Garba et al., 2021; Maidamma et al., 2026).

Table 2: Mean and SD of Effective Dose (mSv)

Centres	N (no of patients)	Region	E (mSv)
	103	Head	3.65(±2.65)
A	111	Chest	1.68(±1.59)
	86	Abdomen	0.74(±0.30)
	132	Head	2.31(±1.36)
B	114	Chest	0.69(±0.33)
	54	Abdomen	0.74(±0.29)
	132	Head	1.14(±0.45)
C	108	Chest	0.68(±0.36)
	60	Abdomen	0.69(±0.29)
	367	Head	2.25(±1.99)
Total	333	Chest	1.15(±1.22)
	200	Abdomen	0.72(±0.29)

The Relationship Between Patient Age Groups and Effective Dose

The relationship between patient age groups and effective dose in Centre A reveals non-uniform distribution of radiation exposure across age brackets (figure 1a). Particularly, patients in the 20-29 and 30-39 age groups appear to receive higher average doses compared to other cohorts in Centre A reveals non-uniform distribution of radiation exposure across age brackets. Particularly, patients in the 20-19 and 30-39 age groups appear to receive higher average doses compared to other cohorts. This is a critical finding given that younger patients (especially those 20 years) are more radiosensitive due to active cellular division and longer remaining lifespans, factors that substantially elevate their lifetime attributable risk (LAR) of cancer, as established by the BEIR VII model.

Figure 1a,b&c: Effective dose against age group in study Centres

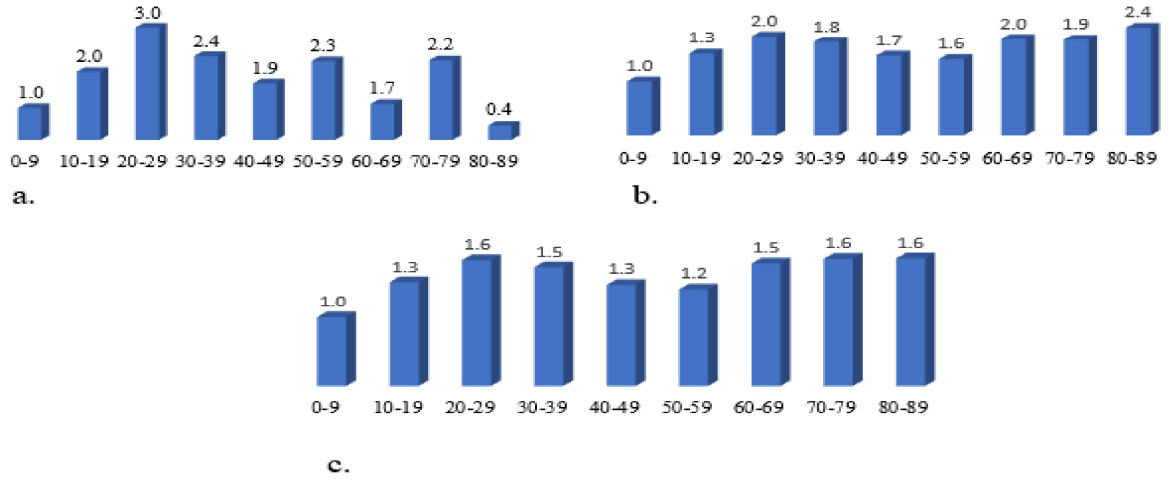


Figure 1b, shows a more consistent dose distribution across age groups compared to Centre A, with effective doses some remaining below the 2 mSv for most age ranges. The highest doses are seen in patients aged 20–29 and 80–89, but even these remain within the lower-risk category as defined by international radiological protection agencies. There remains concern for young patients, particularly in the 0-9 and 10-19 age groups, where any non-essential exposure must be carefully justified. Overall, Centre B demonstrates moderate compliance with dose safety standards, but continuous review and individualized scanning protocols remain essential for long-term patient protection. Centre C, Figure 1c, the dose distribution across age groups indicates the consistent overall exposure among all three centres. Most patient categories received effective doses well below 2 mSv, including those undergoing head, chest, and abdominal CT scans. Despite the lower absolute doses, special attention must still be paid to younger patients (0-19 years) due to their increased susceptibility to radiation-induced carcinogenesis. Although the effective doses in Centre C, are commendable, ongoing surveillance is warranted to ensure consistency across varying body habitus and clinical indications. In conclusion, Centre C's age dose demonstrates commendable performance in minimizing radiation burden, setting a reference standard for the other centres in terms of clinical protocol design and patient safety assurance.

Comparison of centres effective dose with literature

A comparative analysis of the average ED (mSv) for CT examinations across the three anatomical regions (Head, Chest, and Abdomen) performed at three local centres (Centre A, Centre B, and Centre C), benchmarked against established values from selected peer-reviewed literature. ED for head CT scans at Centre A (3.8 mSv) is notably higher than those recorded at Centre B (2.3 mSv) and Centre C (1.1 mSv). When compared to international standards, the value from Centre A closely aligns with the dose reported by (Smith-Bindman et al., 2009) who reported a mean of 3.0 mSv for adult head CT. However, doses from Centre C are substantially lower and are consistent with the findings of (Zamani et al., 2025) and (Virginia Tsapaki et al., 2006) who documented head CT doses of 1.1 mSv and 1.2 mSv, respectively. This variation suggests potential differences in scan protocols, scanner models, and exposure settings (mA, kV, and SL) between local centres, highlighting a possible optimization strategy. Chest CT EDs at the local centres range from 0.7 mSv (Centres B and C) to 1.7 mSv (Centre A). These values are substantially lower than those reported in literature. For instance, (Al-OThman, 2022) and (Smith-Bindman et al., 2009) reported mean doses of 7.3 mSv and 5.0 mSv, respectively.

Abdominal CT Examinations: similarly, EDs for abdominal CT at the local centres 1.8 mSv (Centre A), 0.7 mSv (Centre B), and 0.8 mSv (Centre C) are markedly lower than literature value. The dose from Centre A is the highest among the local centres but still significantly reduced compared to published standards. This trend reinforces the possibility that current CT protocols at the study centres have been optimized for dose reduction without compromising diagnostic utility. Several patients undergoing head CT at UDUTHS received doses ranging from approximately 3.2 to 6.5 mSv, closely matching the average of 3.8 mSv. In contrast, patients scanned at other centres (CCDCS and SSAMDCS) show lower values, consistent with Centres B and C. The wide range of abdominal scan doses, primarily between 0.7 and 2.4 mSv across the dataset, further confirms the lower average values reported in Table 2. Thus, the data provides strong quantitative support for the dose optimization conclusions drawn from Table 3.

Table 3: Comparison of Effective Dose with Literature

Studies	E (mSv) Scan Region		
Centres/Studies	**Head**	**Chest**	**Abdomen**
Centre A	3.8	1.7	1.8
Centre B	2.3	0.7	0.7
Centre C	1.1	0.7	0.8
(Abdullah et al., 2022)	1.8	4.2	8.7
(Al-OThman, 2022)	1.7	7.3	10
(V. Tsapaki et al., 2006)	1.2	5.9	8.2
(Zamani et al., 2025)	1.1	3.7	5.8
(R. Smith-Bindman et al., 2009)	3.0	5.0	10

Comparison of E (mSv) with Scan Parameters

For Centre A, the multiple linear regression model relating effective dose (E) to tube voltage (kV), tube current (mA), and scan length (SL) is given by: E = 1.292 − 0.00264kV + 0.002683mA − 0.01392SL. The overall regression model is statistically significant (F = 29.3, p < 0.001), indicating that the selected scan parameters collectively explain a meaningful proportion of the variation in effective dose. The coefficient of determination (r^2 = 25.4%, shows that approximately one-quarter of the variability in patient effective dose can be explained by changes in kV, mA, and scan length in these centres. Centre B, the regression equation is expressed as; E = −6.01 + 0.0651kV + 0.00735mA − 0.0494SL, and the model demonstrates strong statistical significance (F = 76.70, p < 0.001). The coefficient of determination (r^2 = 47.70%) indicates that nearly half of the variation in effective dose is explained by the three scan parameters. For Centre C, the regression model is:

E = 1.74 + 0.0019kV − 0.00464mA − 0.00478SL,

with the overall model reaching statistical significance (F = 3.58, p = 0.014). However, the explanatory power of the model is very low, with r^2 = 3.03%, indicating that scan parameters explain only a small fraction of the variability in effective dose at this centre. This inverse trend may reflect the influence of advanced automatic exposure control and dose modulation technologies in this newer GE Brivo 16-slice scanner, where increases in mA may occur selectively for larger patients while overall dose efficiency is maintained (Table 4).

Table 4: Regression analysis of Effective dose against Scan Parameters

Centres	*F- value*	r^2	*P-value*
A	29.3	25.4	0.000
B	76.7	47.7	0.000
C	3.58	3.03	0.014

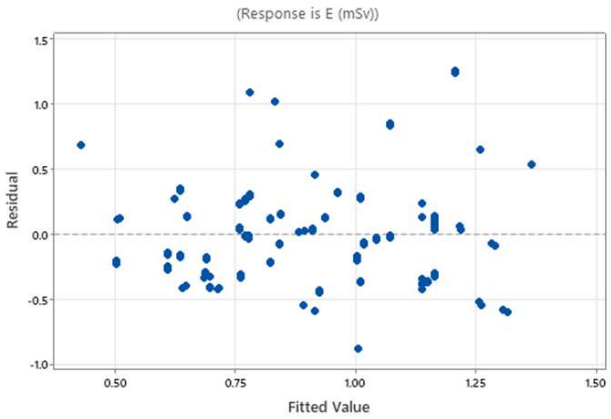
IV. DISCUSSION

Comparatively, Centre B shows the strongest and most predictable relationship between effective dose and scan parameters. Centre A shows moderate dependence with room for optimisation, while Centre C demonstrates advanced technology-driven dose modulation where traditional linear parameter–dose relationships are less dominant. These findings emphasise the importance of centre-specific optimisation strategies and support the development of local Diagnostic Reference Levels (DRLs) tailored to scanner technology and clinical practice in Sokoto State.

Relationship Between ED (mSv) and Scan Parameters in Centre A

Figure 2, the scatter plots with fitted regression lines demonstrate a clear upward trend between effective dose and mA, while kV shows weak dispersion and scan length shows a modest inverse trend. The presence of several large residuals indicates inter-patient variability and reinforces the need for further optimisation and protocol harmonisation in Centre A.

Figure 2: Regression graph of E (mSv) against Scan Parameters in Centre A



Relationship Between ED (mSv) and Scan Parameters in Centre B

Figure 3, the regression plots for Centre B show well defined linear trends, particularly for kV and mA, with relatively narrow scatter around the fitted lines. The lack of fit test is not significant, indicating that the linear model adequately describes the data. However, a few extreme residuals point to occasional protocol deviations or atypical patient examinations, which merit quality assurance review. Overall, Centre B demonstrates the most optimised and predictable relationship between scan parameters and effective dose.

Relationship Between ED (mSv) and Scan Parameters in Centre C

Figure 4, the scatter plots for Centre C show wide dispersion and weak linear trends, consistent with the low r^2 values. Numerous large residuals highlight substantial inter-patient and protocol-driven variability. This suggests that in Centre C, effective dose is more strongly influenced by patient-specific factors, reconstruction algorithms, and vendor-specific dose-reduction technologies than by simple scan parameter settings alone.

Figure 3: Regression graph of E (mSv) against Scan Parameters in Centre B

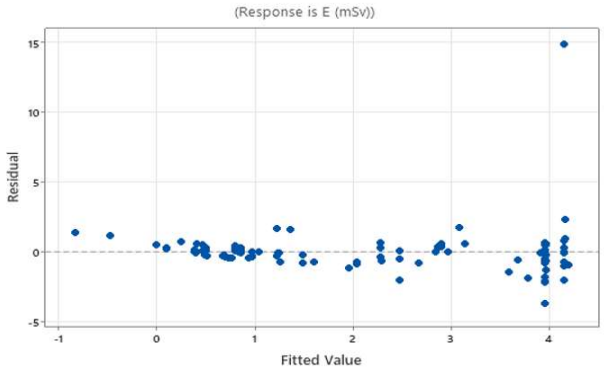
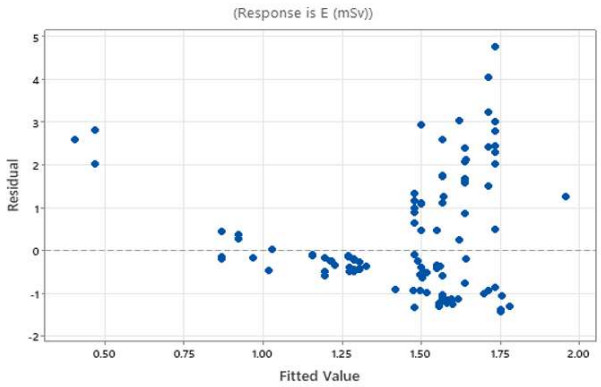


Figure 4: Regression graph of E (mSv) against Scan Parameters in Centre C



V. CONCLUSION

This study revealed substantial inter-centre variability in effective dose for routine CT examinations in Sokoto State despite comparable clinical indications. These differences were primarily driven by variations in scan parameters, scanner technology, and protocol. Regression analysis identified tube current and scan length as the principal determinants of effective dose, although their influence varied across centres, reflecting differences in dose modulation and optimisation practices. Comparison with international literature indicates that while some centres operate within global benchmarks, others demonstrate clear potential for dose optimisation. These findings underscore the need for continuous dose monitoring, protocol standardisation, and targeted staff training to reduce unnecessary radiation exposure. The establishment of locally derived diagnostic reference levels based on measured effective dose values would provide a critical framework for quality assurance and optimisation in Nigeria. Overall, the study highlights the utility of effective dose as a population-level metric for comparison while emphasising the importance of centre-specific optimisation to ensure safe and effective CT practice.

VI. ACKNOWLEDGEMENT

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