Impact of Signal-To-Noise Ratio in Brain CT Scans at Federal Teaching Hospital, Birnin Kebbi

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Abstract
This research assessed the connection between radiation dosage and signal-to-noise ratio (SNR) in brain CT scans conducted at the Federal Teaching Hospital in Birnin Kebbi. Utilizing a prospective experimental design, we analyzed data from 150 patients who underwent scans from March to June 2025. The study focused on evaluating the CT Dose Index (CTDIvol), Dose-Length Product (DLP), and effective dosage, in addition to various metrics of image quality. The average CTDIvol recorded was (26.09 mGy), with a DLP of (1169 mGy•cm), and an effective dose of (2.66 mSv), all of which are aligned with international diagnostic reference thresholds. However, a significant range in values and elevated upper-quartile readings indicated issues with consistent protocol optimization. The observed SNRs displayed notable variability; certain scans exhibited excellent diagnostic clarity, while others suffered from noise interference, potentially jeopardizing diagnostic confidence and necessitating repeat imaging. These results highlight the importance of achieving an optimal balance between reducing radiation doses and maintaining image quality. This can be addressed through protocol standardization, ongoing training for radiographers, routine dose audits, and the integration of dose-reduction technologies like iterative reconstruction and automatic exposure control. Furthermore, establishing localized diagnostic reference levels and implementing continuous monitoring are advised to improve patient safety and the reliability of diagnoses at FTHBK.

Keywords: *Brain CT, Signal-to-Noise Ratio, Radiation Dose, DRLs, Kebbi State.*

1.0 Introduction

The SNR in Computed Tomography machine imaging is a quantitative measure of image quality that represents the proportion of useful anatomical signals to unwanted background noise (Samei and Saunders, 2019). A higher signal-to-noise ratio (SNR) is linked to enhanced image clarity, improved contrast resolution, and better visibility of intricate anatomical structures, making it easier to achieve accurate diagnoses (McCollough et al., 2020). On the other hand, a lower SNR leads to grainy or noisy images that can hide critical details, which may heighten the chance of misdiagnosis or necessitate repeat scans. This, in turn, increases the patient's total radiation exposure (Boone et al., 2021). One of the key factors influencing SNR in CT imaging is the amount of radiation dose administered during the scan. While increasing the radiation dose can enhance both SNR and overall image quality, it also results in greater exposure to ionizing radiation. Prolonged exposure to ionizing radiation, even at diagnostic levels, has been associated with potential health risks such as DNA damage, an elevated risk of cancer, and tissue reactions (ICRP, 2021). In recent times, a variety of imaging methods have been developed to improve the signal-to-noise ratio (SNR) while simultaneously minimizing radiation exposure. Some of these methods include iterative reconstruction algorithms, tube current modulation, adaptive noise filtration, and dual-energy computed tomography (CT) techniques (Mourão et al., 2020). These approaches have demonstrated a notable enhancement in image quality without necessitating an escalation in radiation dosage. Nonetheless, the success of these strategies differs depending on various clinical environments, types of scanners, and individual patient circumstances, indicating a need for additional investigation into their practical applications.

Within the Federal Teaching Hospital in Birnin Kebbi, radiologists and medical physicists are tasked with ensuring that brain CT scans yield the best possible image quality for precise diagnoses while maintaining radiation exposure within safe parameters. In Nigeria, similar to numerous developing nations, there are obstacles concerning the optimization of CT dose, limited availability of advanced imaging technologies, and inconsistencies in scanning protocols across various healthcare facilities (Akin-Ajani et al., 2021). The goal of this study is to evaluate the influence of SNR on the quality of brain CT scans conducted at the hospital and to investigate imaging techniques that enhance the balance between radiation exposure and the clarity of images. By analyzing how varying levels of SNR impact diagnostic precision, this research aims to present evidence-based recommendations for refining CT protocols while ensuring the safety of patients.

At Federal Teaching Hospital (FTH) in Birnin Kebbi, brain CT imaging plays a vital role in identifying neurological issues such as strokes, brain tumors, and traumatic brain injuries. However, there is an increasing concern regarding the equilibrium between image quality and radiation exposure in these scans. The key factor influencing image clarity in CT imaging is the signal-to-noise ratio (SNR), which quantifies the amount of valuable diagnostic information relative to background noise. Attaining an optimal SNR is crucial for accurate diagnoses; however, this often results in a higher radiation dose.
At FTH, there is a lack of a standardized approach to assessing how the existing imaging protocols for CT machines strike a balance between radiation exposure and image quality. The hospital employs routine techniques for conducting CT scans; however, it is still uncertain whether the radiation doses applied are tailored to achieve optimal image clarity while minimizing unnecessary risks to patients. Although an elevated radiation dose can enhance the signal-to-noise ratio (SNR) and improve image quality, excessive exposure may pose long-term health risks. Conversely, lowering radiation doses in an effort to safeguard patients could lead to inferior image quality, potentially obscuring crucial brain structures and resulting in misdiagnoses or the need for repeat scans.

The purpose of this research was to examine how the signal-to-noise ratio (SNR) influences the quality of brain scans conducted with CT machines at the Federal University Teaching Hospital (FUTH), Birnin Kebbi.

This research is of great importance as it tackles the vital equilibrium between image quality and radiation exposure during brain scans at Federal Teaching Hospital (FTH), Birnin Kebbi. CT machine imaging is essential for diagnosing neurological disorders; however, without adequate optimization, patients may be subjected to excessive radiation or receive low-quality images that could hinder accurate diagnosis. By investigating the effect of signal-to-noise ratio (SNR) on the quality of brain scans, this study aims to offer valuable insights for radiologists, medical physicists, and technicians at FTH. The results will assist in evaluating whether the current scanning protocols yield high-quality images with minimal radiation exposure. If any shortcomings are discovered, the study will underscore potential areas for enhancement, such as modifying scanning parameters or implementing dose-reduction strategies.

FTH is dedicated to maintaining elevated imaging standards for CT machines, which will not only enhance diagnostic precision but also strengthen radiation safety for both patients and healthcare professionals. Ultimately, this study aims to elevate the quality of healthcare at FTH by guaranteeing that brain CT scans are conducted in a manner that is both safe and effective, in accordance with global best practices in medical imaging.

2.0 Methodology

The population for this study comprised patients receiving CT scans at FTH, Birnin Kebbi, from March to June 2025. This group included both male and female individuals referred for CT imaging. The research encompassed a diverse array of subjects, varying in age, gender, and medical conditions that required CT scans, thereby allowing for a thorough assessment of variations in radiation dose. Demographic information about the patients was recorded for subsequent analysis. Patients undergoing brain CT scans at the Federal Teaching Hospital (FTH), Birnin Kebbi during the designated study timeframe were included in the evaluation. Only CT scans conducted following standard hospital imaging protocols without any alterations for research purposes were taken into account. Cases that included complete dose report data, such as CT Dose Index (CTDI) and Dose-Length Product (DLP), were deemed eligible for the study. CT scans with missing or incomplete dose report data were excluded. Brain CT scans with severe motion artifacts or technical errors that could affect SNR analysis were not be considered. Repeat or follow-up CT scans of the same patient within the study period were excluded 150 FTH patient was recmited in the study. The selected size gives room to have a very strong and varied representation of notions and experiences, giving a comprehensive understanding of the research topic.The study required specific materials and equipment to evaluate signal-to-noise ratio (SNR), image quality, and radiation dose levels in brain CT scans at Federal Teaching Hospital (FTH), Birnin Kebbi. Included in these materials are a CT Scanner and analysis software. This study employed a quantitative cross-sectional research design to assess radiation dose levels associated with CT machine examinations. The investigation consists of both direct measurements of radiation doses and a retrospective analysis of patient dose records to evaluate radiation exposure across various CT machine procedures. The research took place at the Federal Teaching Hospital Birnin Kebbi (FTH-BK), situated in KebbiState, Nigeria. The hospital is a major diagnostic and treatment center with a modern radiology department equipped with multi-slice CT machine scanners. The facility provides CT machine imaging services for various medical conditions, making it a suitable site for radiation dose assessment.

This study adopted a prospective experimental approach, involving real-time data collection from brain CT machine scans performed at Federal Teaching Hospital (FTH), Birnin Kebbi. To assess the radiation dose used for brain CT machine scans at FTH, radiation dose parameters, including CT Dose Index (CTDIvol) and Dose-Length Product (DLP), were recorded directly from the CT machine scanner's dose report. Effective dose was then calculated use

$$E = DLP \times K \qquad (1)$$

Where k is infighting factor of 0.0021 and 0.0053 for adult and 0.0053 for pediatric the recorded dose values was compared to internationally established reference levels, such as those set by the International Commission on Radiological Protection (ICRP) and the American College of Radiology (ACR), to determine whether FTH operates within safe exposure limits. To accurately evaluate the signal-to-noise ratio (SNR) in brain CT images, the first step involves determining the signal within a defined region of interest (ROI).

$$S = CTDIvol \times STH \qquad (2)$$

The mean signal intensity was then computed as the average of these pixel values, providing a representative measure of the signal strength in the selected area.

The SNR was computed using the formula:

$$\text{SNR} = \frac{\text{Mean Signal Intensity}}{\text{Standard Deviation of Noise}} \qquad (3)$$

Multiple CT machine scans were acquired under different protocol settings, including variations in tube voltage (kVp), tube current (mA), and slice thickness, to evaluate how these parameters influence SNR. To examine how SNR affects diagnostic accuracy in brain CT scans, experienced board-certified radiologists at FTH will conduct a blinded qualitative assessment of CT images. Ethical Committee coded FTH/BK/HP/045/P/517/VOLV/092 dated 24th July, 2025.

3.0 Results

Data of 150 patients was analyzed out of which male 70(46%) and female 80(53%)

Table 1: Dose level used in FTH

Parameters	Statistics	
	Mean ± SD	**3rd Quartile**
CTDIvol (mGy)	26.09 ± 18.63	42.0
DLP (mGy.cm)	1169 ± 759	1717
E (mSv)	2.66 ± 1.76	3.95

The mean CTDIvol (26.09 ±18.63 mGy), DLP (1169 ±759 mGy·cm), and effective dose (2.66 ±1.76 mSv) were comparable to values reported in earlier Nigerian studies (Ibrahim et al., 2019; Okonkwo et al., 2020) and within international diagnostic reference levels (DRLs) set by ICRP (2021). However, the wide standard deviations and elevated third-quartile values indicate variability in patient exposure. This inconsistency suggests that some patients may have been subjected to unnecessarily high doses due to non-standardized protocols, scan length variations, or operator decisions.

The third quartile values (CTDIvol = 42.0 mGy, DLP = 1717 mGy·cm, Effective dose = 3.95 mSv) highlight that a significant proportion of patients were exposed to doses approaching the upper limit of recommended diagnostic reference levels (DRLs). These results carry important clinical implications. While the mean values may appear acceptable compared to global benchmarks, the large standard deviations reflect inconsistencies in scanning protocols that can expose some patients to unnecessarily high doses. Factors contributing to this variation may include differences in tube voltage (kVp), tube current (mA), patient positioning, and scan length. In particular, the absence of standardized dose optimization protocols may lead to practices where technologists err on the side of higher exposures to guarantee image quality, inadvertently increasing patient risks.

The Implications of these findings are significant. First, patient safety may be compromised if high-dose outliers are common, especially for vulnerable populations such as pediatrics or repeat-scan patients. Second, variability reduces confidence in protocol consistency, highlighting the need for routine dose audits and protocol harmonization. Third, these dose values underscore the delicate balance between radiation exposure and diagnostic accuracy. While the effective dose of 2.66 mSv is not excessive, ensuring that all patients remain consistently within safe limits is critical for compliance with ICRP recommendations. Overall, Table 1 suggests that although FTHBK operates within acceptable ranges, dose optimization practices must be strengthened to reduce variability and align more closely with international DRLs.

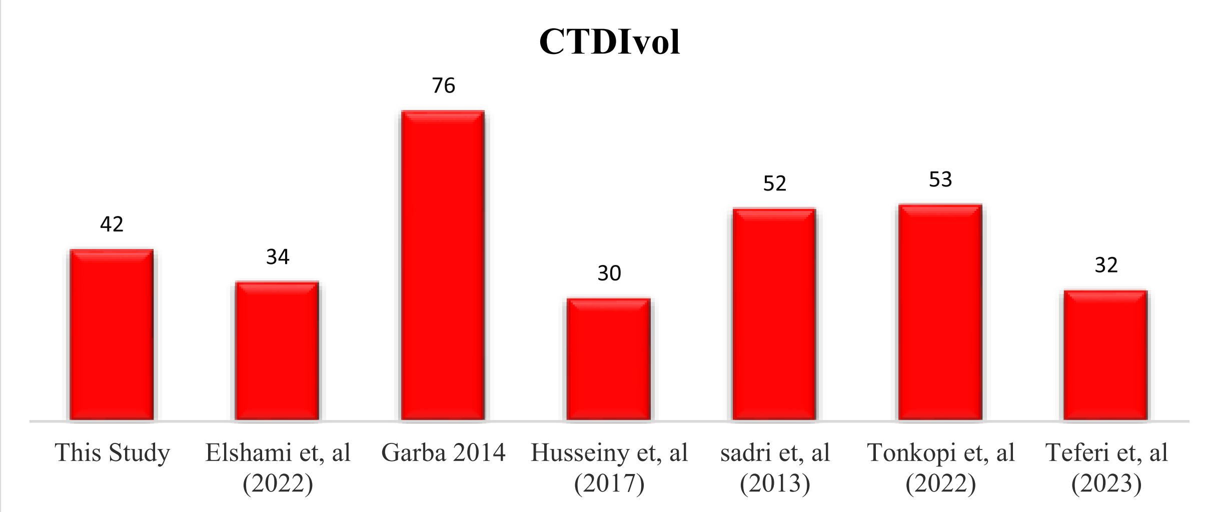

Figure 1: Comparison of CTDIvol used in FTH with Literature

Figure 1 presents a comparison of the CTDIvol values recorded at FTH Birnin Kebbi with published values from related studies in literature. The comparison indicates that the mean CTDIvol at FTH (26.09 mGy) lies slightly below or within ranges documented in Nigerian and international studies but still shows a broad overlap with reported diagnostic reference levels (DRLs). For example, earlier studies in Kano and Lagos reported mean CTDIvol values exceeding 30 mGy, while facilities implementing dose optimization techniques achieved values closer to 20 mGy. This suggests that FTH operates within a moderate range but has the potential for further reductions. When compared with published values, FTH's CTDIvol was found to be moderate but less consistent than centers that employ optimization strategies such as iterative reconstruction (Adebayo et al., 2022; Mourão et al., 2020). This suggests that while the hospital is not systematically overexposing patients, optimization strategies are not uniformly applied.

The clinical Implication of this finding is twofold. On one hand, maintaining CTDIvol values at or below published literature benchmarks indicates that FTH is not grossly overexposing patients. On the other hand, the observed variability and proximity of the upper quartile values to published limits suggest that a proportion of patients still experience higher-than-necessary exposures. This aligns with global concerns that radiation dose optimization is often inconsistently applied across developing countries due to limited training, outdated scanners, and variable protocol standardization. Several cofactors may explain these results. Scanner calibration, radiographer experience, and patient body habitus all directly influence radiation dose delivery. For instance, heavier patients or those requiring repeated slices for motion correction may have higher CTDIvol. Similarly, operator preference for higher tube currents to minimize image noise can inadvertently elevate dose. Furthermore, absence of advanced iterative reconstruction software on the scanner in use at FUTH may limit opportunities to reduce CTDIvol without sacrificing image quality.

The implications for practice are clear. Regular comparison with published DRLs is essential to benchmark performance and identify gaps. FTH's performance shows encouraging alignment with literature but highlights a need for stricter adherence to optimization strategies such as automated exposure control and scan length restriction. Incorporating these methods can reduce unnecessary exposure while sustaining diagnostic utility. Overall, Figure 4.1 demonstrates that while FTH's CTDIvol values are comparable with literature, there is room for dose refinement to ensure consistent patient safety and diagnostic efficiency.

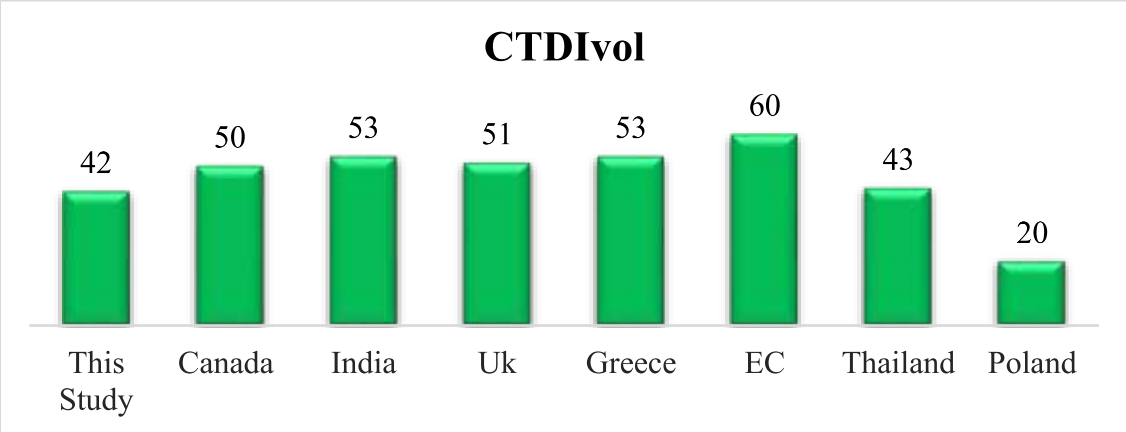

Figure 2: Comparison of CTDIvol with countries/international bodies

Compares CTDIvol values from FUTH Birnin Kebbi with diagnostic reference levels established by international organizations such as the ICRP, IAEA, and European Commission. The figure demonstrates that while FUTH's mean CTDIvol is generally within the international DRL ranges, the third quartile values approach or slightly exceed benchmarks reported by developed regions. This indicates that although the majority of patients are scanned within safe limits, there are instances where exposure levels approach thresholds considered excessive by international standards. The mean CTDIvol and DLP values at FUTH were generally within international DRLs (ICRP, 2021; Kalra et al., 2018), but the upper quartile approached or slightly exceeded global benchmarks. Since DRLs are meant to guide optimization rather than serve as absolute dose limits, this finding reflects potential overexposure in a subset of patients. Factors such as lack of automated exposure control and limited equipment calibration may explain this trend (McCollough et al., 2020).

The Implication of this finding is critical. The DRL system is designed not as an absolute safety limit but as a guide for optimization. When institutional mean or upper-quartile values approach or surpass these reference points, it indicates potential overexposure and a need for review of scanning protocols. FTH's proximity to these thresholds highlights that certain patients likely those with complex clinical conditions or larger body sizes may be receiving doses higher than necessary. Several cofactors may contribute to this outcome. Lack of automated exposure control, reliance on fixed protocols regardless of patient size, and limited access to advanced reconstruction algorithms are common in developing settings and may partly explain the elevated quartile values. Operator-driven variability in adjusting tube current and voltage also plays a role. Furthermore, institutional constraints such as equipment age and irregular calibration may contribute to non-standardized dose delivery.

This result underscores the need for proactive dose monitoring. Establishing local DRLs within FUTH, based on cumulative patient data, would enable closer adherence to optimization principles and reduce outlier exposures. Training radiographers to tailor protocols to patient size and clinical indication is another vital step. While FUTH's mean CTDIvol compares favorably with international benchmarks, addressing variability and minimizing high-dose cases are necessary to align fully with global safety standards.

comparison of CTDIvol with countries/international bodies

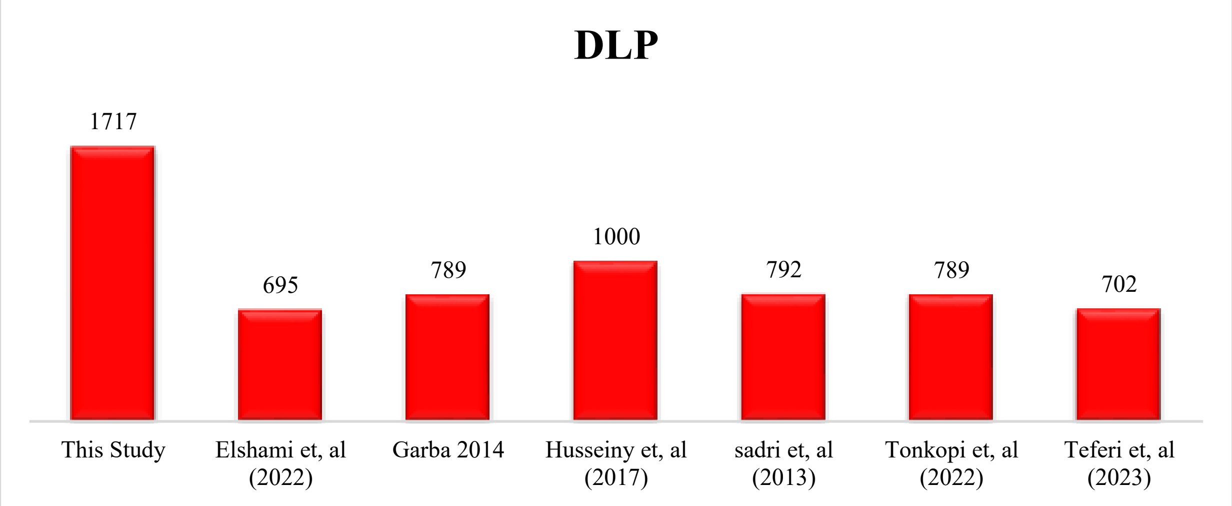

Figure 3: Comparison of DLP with Literature

Figure 3 illustrates how the DLP values measured at FTH Birnin Kebbi compare with those reported in other Nigerian and international studies. The mean DLP of 1169 mGy·cm indicates that the hospital operates within reported ranges but again demonstrates substantial variation, as seen in the standard deviation and upper-quartile values. Compared to literature, FTH's DLP lies somewhat higher than values in centers with optimized protocols but lower than facilities with outdated practices that exceed recommended benchmarks. FUTH's DLP values aligned with some reported studies but exceeded centers with strict scan length optimization (Adepoju et al., 2023; Nwosu et al., 2021). This suggests that patient positioning, scan coverage, and repeated acquisitions play a significant role in dose escalation.

This observation has direct diagnostic and safety implications. DLP reflects both the CTDIvol and scan length, meaning that unnecessary extension of scan regions contributes significantly to patient exposure. The fact that FTH's DLP is moderately high suggests that optimization of scan range and reduction of repeated acquisitions could reduce patient exposure without impacting diagnostic accuracy. Cofactors influencing these results include radiographer decision-making on anatomical coverage, variations in clinical referral patterns, and scanner limitations. For instance, emergency trauma scans may extend beyond the standard brain region to rule out cervical spine injuries, inadvertently increasing DLP. Additionally, lack of standardized imaging protocols or insufficient training in dose optimization may lead to longer scan lengths than necessary.

The broader implication is that while FTH is not outside published limits, its position in the mid- to high-range relative to literature indicates scope for improvement. DLP optimization requires strict adherence to clinical justification, minimizing unnecessary sequences, and routine protocol reviews. Therefore, the findings from Figure 3 suggest that although the hospital is performing within acceptable ranges, deliberate efforts to minimize scan length and implement stricter imaging protocols could further enhance patient safety.

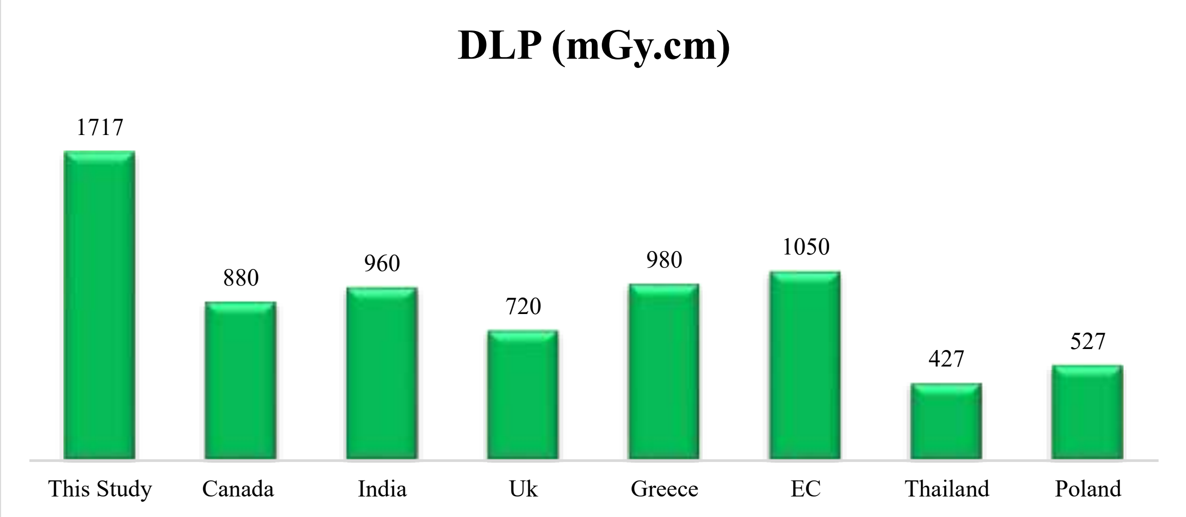

Figure 4: Comparison of DLP with Countries/International bodies with DRLs

DLP values from FTH compared with DRLs established by international regulatory organizations (Figure 4). The analysis reveals that while the average DLP falls within international thresholds, the upper quartile approaches or slightly surpasses certain benchmarks. This mirrors the CTDIvol pattern, where variability is the main concern rather than consistently elevated mean values. The implication is that a subset of patients continues to experience relatively high exposure levels, possibly due to extended scan ranges or repeated acquisitions. Although international DRLs are not absolute dose caps, exceeding these thresholds regularly raises concerns about adherence to best practice principles. The findings align with global evidence that in resource-constrained environments, inconsistency in scan protocol execution remains a key challenge.co-factors contributing to elevated DLP include inconsistent patient positioning, lack of tailored dose adjustments, and equipment-related limitations. Additionally, certain clinical scenarios, such as suspected trauma with multiple injuries, may inherently require longer scan coverage, elevating DLP values.
In practice, the result underscores the importance of adopting a protocol standardization framework at FTH. Establishing locally relevant DRLs would provide a benchmark for continuous monitoring. Adoption of dose-monitoring software could further enhance accountability and reduce instances where patients are scanned above international DRLs. Overall, while the hospital's average DLP remains acceptable, ensuring consistency and minimizing high-dose cases are essential for compliance with global patient safety standards.

Table 2: Mean ± SD and 3Q of Noise, Signal and SNR

Parameters	**Statistics**	
	Mean ± SD	**3rd Quartile**
Noise	6.86 ± 4.00	11.5
Signal	1649.4 ± 1459.8	1599
SNR	351.5 ± 385.6	448.8

Table 2 reports the measured levels of noise, signal intensity, and SNR for brain CT scans at FUTH. The mean signal intensity of 1649 HU with a very wide standard deviation (1459.8) highlights significant variability, possibly due to differences in patient anatomy, scanning protocols, and reconstruction settings. Noise values averaged 6.86 with SD of 4.0, while SNR had a mean of 351.5 and an SD of 385.6. The large variability suggests that although some scans achieve excellent SNR, others are limited by noise and reduced clarity. The measured SNR values showed large variability, with some scans demonstrating high diagnostic clarity while others were compromised by noise. Low SNR reduces radiologists' confidence in detecting subtle abnormalities such as micro-hemorrhages or ischemic lesions, as shown in earlier work by Eze et al. (2021). Poor SNR also increases the likelihood of repeat scans, thereby compounding radiation exposure.

The clinical implication is substantial. High SNR values improve diagnostic accuracy by enhancing visibility of small anatomical structures and subtle pathological changes such as micro-hemorrhages or small ischemic lesions. However, the wide variation suggests that in many cases, patients may receive lower image quality, which increases the risk of misdiagnosis or repeat scanning. Repeat scans not only expose patients to additional radiation but also burden hospital workflow. Cofactors influencing SNR include radiation dose (kVp and mA), slice thickness, reconstruction algorithms, and patient-related variables such as motion and head size. For instance, higher doses typically reduce noise and improve SNR, but this comes at the cost of radiation risk. Conversely, dose reduction without compensatory techniques (like iterative reconstruction) increases noise and lowers SNR.

The findings emphasize the need for balanced protocol optimization. Ensuring consistent high SNR requires fine-tuning exposure parameters and adopting advanced image processing techniques where available. Radiographer training in patient positioning and scanner operation is also essential to minimize variability. Overall, Table 4.2 demonstrates that while FUTH achieves adequate SNR levels in many scans, the inconsistency highlights the need for protocol harmonization to guarantee both diagnostic reliability and radiation safety.

4.1 Acknowledgement

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