ESTIMATION OF ENTRANCE SKIN DOSE IN ANALOGUE X-RAY FACILITIES OF SOUTHERN DELTA STATE, NIGERIA: A MATHEMATICAL APPROACH TO RADIOLOGICAL PROTECTION

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ABSTRACT

Radiation dose optimisation in diagnostic radiography is essential for patient safety and adherence to international standards. In many developing regions, analogue X-ray systems remain in use, raising concerns about elevated exposure levels. This study evaluated entrance skin dose (ESD) and effective dose in four government-owned hospitals in southern Delta State, Nigeria, all operating analogue X-ray equipment. Patient examinations included three routine projections: chest (AP), pelvis (SV), and abdomen (LS). The mean ESD values obtained were BGH1 (1.04 mGy), BGH2 (0.94 mGy), DEXC1 (1.78 mGy), and DEXC2 (0.87 mGy). These values exceeded the international diagnostic reference level of 0.4 mGy, though they were lower than those reported in several previous studies and marginally higher than results published by the same authors elsewhere. The elevated doses may reflect suboptimal operator techniques and inadequate equipment maintenance. Although quality control assessments are mandated quarterly, inconsistent compliance likely contributes to the observed deviations. The findings emphasize the need for stricter enforcement of quality assurance protocols and enhanced operator training to reduce patient radiation exposure. While the recorded doses remain within diagnostic ranges, optimization of radiographic practice is imperative to align with international benchmarks and safeguard patient health.

Keywords: Effective dose, X-ray machines, Radiation safety, ESD, Examination

INTRODUCTION

Radiation safety in medical imaging remains a global concern, particularly due to the risks associated with ionizing radiation exposure. While high-level exposures are known to cause deterministic effects such as skin burns and cataracts, diagnostic radiology typically involves low-dose exposures where the risks are stochastic and probabilistic in nature, including a small but non-negligible potential for carcinogenesis and genetic effects (Usikalu et al., 2024; Fataftah et al., 2024; Liu et al., 2025). Despite these risks, ionizing radiation is indispensable in modern healthcare, forming the backbone of diagnostic procedures such as radiography, fluoroscopy, and CT scans (Najjar, 2023; John & Mina, 2024). Globally, medical applications account for more than 95% of man-made radiation exposure, with diagnostic radiology contributing significantly to collective patient dose (Sidi et al., 2024). In Nigeria, and particularly in southern Delta State, analogue X-ray facilities remain widely used, yet patient dose data from these facilities are scarce. This lack of baseline information poses challenges for establishing diagnostic reference levels (DRLs) and implementing effective radiation protection measures. Entrance Skin Dose (ESD), expressed in milligray (mGy), is a key parameter for assessing patient exposure during diagnostic examinations and serves as a practical descriptor for DRLs (Haider et al., 2024).

Accurate measurement of ESD requires consideration of technical parameters such as tube voltage (kVp), tube current-time product (mAs), focus-to-skin distance (FSD), backscatter factor (BSF), and tube output (Davis, 1999; Papadakis et al., 2023; Huang et al., 2024; Hassan & Mraity, 2024). In resource-limited settings where advanced dosimetry equipment may not be available, mathematical dose estimation methods provide a pragmatic and literature-supported alternative for quantifying patient exposure. These methods allow facilities to identify potential dose reduction strategies while maintaining diagnostic image quality in line with the ALARA (As Low As Reasonably Achievable) principle (Bamanga et al., 2024).

This study therefore seeks to estimate the ESD for patients undergoing diagnostic X-ray examinations in analogue facilities across southern Delta State, Nigeria, using mathematical dose estimation techniques. By generating local dose data, the research aims to support radiological protection practices, contribute to the establishment of DRLs, and promote safer diagnostic imaging in the region.

MATERIALS AND METHODS

Study Area and Facilities

The study was conducted in four radio-diagnostic centres located in the southern part of Delta State, Nigeria. These centres included Government General Hospitals and Health Centres, all of which operated analogue X-ray machines.

Patient Selection and Demographics

Adult patients undergoing routine diagnostic radiography were included. The typical weight range was 60–80 kg, consistent with reference patient standards recommended by the International Commission on Radiological Protection (ICRP). Pediatric and atypical body habitus cases were excluded to reduce variability. Where patient-specific data were unavailable, standard reference patient assumptions were applied.

Quality Control Procedures

Extensive quality control (QC) checks were performed on all X-ray machines prior to dose estimation. The following tests were conducted in line with IEC and IAEA guidelines:

i. Tube output consistency (variation $\leq \pm 5\%$).
ii. kVp accuracy (tolerance $\pm 5\%$).
iii. Exposure time accuracy (tolerance $\pm 5\%$).
iv. Filtration/HVL measurement to confirm minimum total filtration equivalent to 2.5 mm Al at 70 kVp.

v.   Focus-to-skin distance (FSD) calibration using mechanical rulers.

All machines were found to operate within acceptable tolerances. Calculated outputs were cross-checked against published output curves for similar analogue systems to validate performance.

Data Collection

Patient examinations included the most frequently performed projections:

i.   Chest (AP),
ii.   Pelvis (LA),
iii.   Abdomen (LS).

For each examination, exposure parameters (kVp, mAs, FSD, and tube filtration T) were recorded according to Nigeria Basic Ionizing Radiation Regulation (NBIRR, 2003) protocols.

Dose Estimation Method

Due to the unavailability of thermoluminescent dosimeters (TLDs), an indirect mathematical approach was adopted. The Chuan and Tsai expression, as applied by Alghoul et al. (2017), was used to estimate Entrance Skin Dose (ESD) :

$$\text{ESD (mGy)} = C \left(\frac{Kvp}{FSD}\right)^2 \left(\left(\frac{mAs}{mmAL}\right)\right) \qquad (1)$$

Where ESD is the entrance skin dose, kvp is the x-ray peaks tube voltage, mAs is the exposure value which means that tubes current times exposure time, FSD is the focus to skin Distance (cm), T is the tube filtration (mmAL) and C is a constant (0.2775) (Vatsa et al., 2022).

Effective Dose Calculation

Effective dose (E) was calculated using ICRP tissue weighting factors (ICRP Publication 103, 2007). The formula is given as

$$E = \sum_T W_T W_R \ D_{T.R} \qquad (2)$$

where E is the effective dose, W_T is the tissue weighting factor, W_R is the radiation weighting factor, $D_{T.R}$ is the absorbed dose in tissue from radiation R summing over the tissue. The standard value applied are gonads (0.20), lungs (0.12), skin (0.01) and W_R for x-ray is 1.

Uncertainty Analysis

Uncertainty in ESD estimation was evaluated by propagating variations in key parameters:

i.   **kVp** ($\pm 5\%$),
ii.   **mAs** ($\pm 10\%$),
iii.   **FSD** ($\pm 10\%$).

Overall uncertainty in calculated ESD values was estimated to be within ± 15–20%, consistent with reported ranges for indirect dose estimation methods.

Regulatory Benchmarks

The European Commission (EC, 1996) Diagnostic Reference Levels (DRLs) were adopted as the primary benchmark for comparison, as they remain widely recognized in international radiological protection. Other guidelines (e.g., NRPB, NBIRR) were referenced for contextual comparison only.

RESULTS AND DISCUSSION

Exposure Parameters and ESD Outcomes

Table 1 summarizes the exposure parameters (kVp, mAs, FSD, FFD, and tube filtration) recorded across the four radiodiagnostic centres. The consistently higher ESD values observed at DEXC1 appear to coincide with the combined use of relatively high mAs (> 5 mAs) and shorter FSD (< 30 cm). This parameter combination increases photon fluence at the patient surface, suggesting that technique-driven dose inflation rather than patient-related factors was the primary contributor. By contrast, centres such as DEXC2, which maintained lower mAs and longer FSD, recorded lower mean ESD values (0.87 mGy).

Parameter sensitivity is evident across all centres. For example, increasing kVp improves beam penetration but also elevates ESD if not balanced by reductions in mAs. Conversely, lowering mAs reduces dose but risks compromising image quality. These trade-offs highlight the importance of optimizing exposure settings in line with international standards (Physics in Medicine & Biology; Radiation Protection Dosimetry).

Table 1: Exposure Parameters for Different X-ray Examination and Estimated ESD in the Southern Part of Delta State

X-ray Centres	Examination	Projection	EXPOSURE PARAMETERS						
			KVP	Time(s)	Filtration(T)	mAs	FFD	FSD	ESD
	Chest	AP	60	1.25	2.5	2.16	65	36	0.66
	Chest	AP	60	1.10	2.5	5.60	65	32	2.18
	Chest	AP	60	1.50	2.5	2.52	65	34	0.87
BGH$_1$	Chest	AP	60	1.53	2.5	2.53	65	28	1.28
	Chest	AP	60	1.51	2.5	2.57	65	29	1.22
	Chest	AP	60	1.50	2.5	2.51	65	29	1.19
	Pelvic/HIP	LATERAL(SV)	60	1.50	2.5	1.60	65	29	0.75
	Pelvic/HIP	LATERAL(SV)	60	1.52	2.5	1.59	65	30	0.70
	Pelvic/HIP	LATERAL(SV)	60	1.53	2.5	2.11	65	32	0.82
	Pelvic/HIP	LATERAL(SV)	60	1.50	2.5	2.31	65	33	0.84
	Pelvic/HIP	LATERAL(SV)	60	1.35	2.5	2.50	65	30	1.11
	Chest	AP	65	1.50	2.0	2.5	65	31	1.22
	Chest	AP	65	1.52	2.0	2.53	65	30	1.64
	Chest	AP	60	1.2	2.0	1.60	65	30	0.88
	Chest	AP	60	1.28	2.0	2.54	65	40	0.79
	Chest	AP	65	1.28	2.0	2.54	65	39	0.97
BGH$_2$	Chest	AP	70	1.66	2.0	1.50	65	33	0.93
	Chest	AP	70	1.30	2.0	2.5	65	39	1.11

X-ray Centres	Examination	Projection	EXPOSURE PARAMETERS						
			KVP	Time(s)	Filtration(T)	mAs	FFD	FSD	ESD
	Chest	AP	70	1.43	2.0	3.60	65	32	2.38
	Chest	AP	70	1.53	2.0	3.40	65	32	2.25
	Chest	AP	65	1.50	2.0	1.59	65	28	1.18
	Chest	AP	60	1.52	2.0	1.55	65	30	0.86
	Abdomen (Spine)	LS	60	1.55	2.0	1.38	65	40	0.43
	Abdomen (spine)	LS	60	1.43	2.0	1.45	65	36	0.55
	Chest	AP	65	2.53	1.9	1.60	60	40	0.61
	Chest	AP	65	2.55	1.9	2.60	60	31	1.66
	Chest	AP	60	2.50	1.9	2.5	60	34	1.56
DEXC$_1$	Chest	AP	80	3.5	1.9	2.56	60	28	2.06
	Chest	AP	60	1.54	1.9	2.20	60	29	1.37
	Chest	AP	65	1.55	1.9	2.35	60	29	1.72
	Chest	AP	65	2.10	1.9	5.01	60	29	2.83
	Chest	AP	60	2.10	1.9	5.20	60	30	3.48
	Chest	AP	60	1.60	1.9	1.16	60	32	0.40
	Chest	AP	60	1.55	1.9	2.20	60	33	1.28
	Chest	AP	70	1.60	1.9	2.15	60	34	1.33
	Chest	AP	80	1.60	1.9	2.40	60	29	2.66
	Chest	AP	65	2.43	1.9	3.15	60	20	2.15
	Chest	AP	65	2.15	1.9	3.20	60	32	1.92
DEXC$_2$	Chest	AP	60	2.50	1.9	2.10	60	40	0.68
	Chest	AP	60	1.60	1.9	2.40	60	34	1.09
	Chest	AP	60	2.10	1.9	2.50	60	36	1.01
	Chest	AP	65	2.10	1.9	3.60	60	33	2.03
	Chest	AP	60	5.00	1.9	3.20	60	30	1.86
	Chest	AP	60	2.20	1.9	1.60	60	32	0.82
	Pelvic/HIP	LATERAL(SV)	60	1.51	1.9	1.61	65	29	1.00
	Pelvic/HIP	LATERAL(SV)	62	1.40	1.9	1.62	65	30	1.01
	Pelvic/HIP	LATERAL(SV)	60	1.50	1.9	1.60	65	32	0.82
	Abdomen (spine)	LS	60	1.54	1.9	1.37	65	40	0.44
	Abdomen (spine)	LS	60	1.53	1.9	1.39	65	41	0.43

Comparison with Diagnostic Reference Levels

Table 2 presents mean ESD values for chest (AP), pelvis (SV), and abdomen (LS) examinations. When compared against the European Commission (EC, 1996) reference value of 0.4 mGy, all centres exceeded the benchmark. However, reliance on a single DRL may oversimplify compliance assessment. Projection-specific DRLs reported in other studies (e.g., chest AP ~0.3–0.5 mGy; pelvis ~0.7–1.0 mGy; abdomen ~1.0–1.5 mGy) provide a more nuanced comparison. Within this context, chest exposures at BGH1 and DEXC1 (mean ~1.23–1.38 mGy) are clearly elevated, while abdominal exposures at BGH2 and DEXC2 (~0.43–0.49 mGy) fall closer to international ranges.

Sources of Variation

Differences in patient habitus, positioning practices, and operator technique may contribute to observed variability,

although these factors were not independently quantified in this study. Thus, such explanations remain plausible but speculative. The age of the analogue X-ray machines and potential deviations in operator technique likely compounded dose variability.

Uncertainty Considerations

The use of a mathematical dose model introduces uncertainties, particularly in facilities with ageing analogue equipment. Tube output stability, filtration accuracy, and calibration drift can each contribute to dose estimation errors. Propagated uncertainties from kVp ($\pm 5\%$), mAs ($\pm 10\%$), and FSD ($\pm 10\%$) suggest overall ESD uncertainty in the range of ± 15–20%. These limitations should be acknowledged when interpreting compliance with DRLs.

Table 2: Estimated Mean Values for ESD in Different X-ray Examinations Compared with Global Average Value

X-Ray Centres	Examination	Projection	Present work ESD Range (mGy)	Present Study mean ESD (mGy)	E.C 1996 (mGy)	IAEA 1996 (mGy)	IVRPB 2000 (mGy)	KVP	mAs
BGH₁	Chest	AP	(0.66-2.18)	1.23	0.3	0.3	0.2	60	2.98
	Pelvic	LA (SV)	(0.70-1.11)	0.84	10	5	4	60	2.02
	Average			**1.04**	-	-	-		
BGH₂	Chest	AP	(0.76-2.38)	1.38	0.3	0.3	0.2	65	2.42
	Abdomen	(LS)	0.43-0.55)	0.49	10	2.5	2.5	60	1.42
	Average			**0.94**	-	-	-		
DEXC₁	Chest	AP	(0.40-3.48)	1.78	0.3	0.3	0.2	65	3.12
	Average			**1.78**	-	-	-		
									2.03
	Chest	AP	(0.82-2.03)	1.24	0.3	0.3	0.2	60	1.61
	Pelvic	LA (SV)	(0.82-1.01)	0.94	10	5	4	61	1.38
DEXC₂	Abdomen	LS	(0.43-0.44)	0.43	10	2.5	2.5	60	
	Average			**0.87**	-	-	-		

Effective Dose and Optimisation

Table 3 presents calculated effective doses. Chest AP examinations yielded the highest effective dose, reflecting the large field size and radiosensitive lung tissue. Pelvic lateral exposures were moderate, while abdominal supine doses were lowest. Although effective doses were slightly higher than literature values (Ciraj et al., 2005; Wall & Hart, 1997), they remain well below thresholds for deterministic effects. From an optimization perspective, cumulative exposure is a more pressing concern. Repeat chest examinations, common in clinical practice, could significantly increase patient risk over time. Integrating effective dose assessments into justification audits would help ensure that examinations are clinically warranted and that exposure is minimized in line with the ALARA principle.

Table 3: Calculated Effective Dose in Each Radiographic X-ray Examination

X-ray Examination	Effective Dose (mSv)
Chest AP	0.68
Pelvic (Lateral SV)	0.34
Abdomen Supine (LS)	0.19

CONCLUSION

This study demonstrates that patient entrance skin doses (ESD) in analogue X-ray facilities across southern Delta State consistently exceeded international diagnostic reference levels (EC, 1996). The elevated values observed are unlikely to reflect unavoidable clinical demand but rather point to suboptimal practice conditions. In particular, higher ESDs coincided with the combined use of elevated mAs and shorter focus-to-skin distances, underscoring the sensitivity of patient dose to exposure parameter selection. The slightly higher effective doses compared with literature values further suggest that ageing equipment and inconsistent operator techniques contributed to dose inflation. These findings highlight the need for systematic improvements in radiological practice. Regular patient dose audits, stricter enforcement of quality assurance protocols, and targeted operator training in exposure optimization are practical steps that can reduce unnecessary radiation burden. Embedding these measures within routine clinical governance will help align local practice with international standards, safeguard patients against cumulative exposure risks, and ensure that diagnostic imaging continues to deliver benefits while adhering to the ALARA principle.

REFERENCES

Adelayi, M. O., & Ajayi, O. S. (2023). Evaluation of entrance skin dose from paediatric diagnostic X-ray examination. *Open Journal of Radiology, 13*, 26–33. https://doi.org/10.4236/ojrad.2023.131003

Alghoul, A., Abdalla, M. M., & Abubaker, H. M. (2017). *Mathematical evaluation of entrance surface dose (ESD) for patients examined by diagnostic X-rays. Open Access Journal of Science, 1*(1), 8–11. https://doi.org/10.15406/oajs.2017.01.00003

Asogwa, C. O., Chiegwu, H. U., Omojola, A. D., & Onwughalu, E. M. (2021). Assessment of radiation dose to pediatric patients during routine digital chest X-ray procedure in a government medical centre in Asaba, Nigeria. *Medical Science and Discovery.* https://doi.org/10.36677/msd.21486832

Ciraj, O., Marković, S., & Koštitics, D. (2005). First results on patient dose measurements from conventional diagnostic radiology procedures in Serbia and Montenegro. *Radiation Protection Dosimetry, 113*(3), 330–335.

Davies, M., Jones, A., Smith, R., & Taylor, P. (1999). Patient dose audit in diagnostic radiography using custom designed software. *Radiography, 3*(1), 17–25. https://doi.org/10.1016/S1078-8174(99)80005-6

Egbe, N. O., Inyang, S. O., Ibeagwa, O. B., & Chiaghanam, N. O. (2009). *A baseline study of entrance dose and image quality for lumbar spine radiography in Calabar, Nigeria.* **Radiography, 15**(4), 306–312. https://doi.org/10.1016/j.radi.2008.09.004

Eseka, K., Molua, O. C., Morka, J. C., & Ukpene, A. O. (2022). Chest X-ray ESD and ESAK assessment in a few diagnostic radiological facilities in Delta State. *Journal of Healthcare Treatment Development, 2*(6). https://doi.org/10.55529/jhtd.26.17.29

Esu, E. O., Chiegwu, H. U., Omojola, A. D., & Eze, E. M. (2021). Estimation of entrance skin dose and effective dose from abdomen radiography in two diagnostic facilities in Aba, Abia State, South-East Nigeria. *World Scientific News, 161*, 143–156

European Commission; EC (1996). European guidelines on quality criteria for diagnostic radiographic images. EUR 16260 EN Brussels

Fataftah, J., Tayyem, R., Al-Dwairy, S., Al Manasra, A. R., Ibrahim, A., Al Ryalat, R., Alwreikat, M., Al-Shraah, H., Alharbi, R., & Alharbi, B. (2024). *Awareness of radiation hazards and knowledge of radioprotective measures among radiologists and non-radiology staff: A cross-sectional survey.* Egyptian Journal of Radiology and Nuclear Medicine, 55, Article 128. https://doi.org/10.1186/s43055-024-01300-4

Faulkner, K., Broadhead, D. A., & Harrison, R. M. (1999). Patient dosimetry measurement methods. *Applied Radiation and Isotopes, 50*(1), 113–122. https://doi.org/10.1016/S0969-8043(98)00160-7

Gnowe, G., Ekobena, H. P. F., Mbo, J., & Neossi, M. G. (2019). *Exposure levels of adult patients during radiographic examinations: Sinuses and coastal grill cases at the Ngaoundere Regional Hospital, Cameroon.* Radiology Research and Practice, 2019**,** Article 5452149. https://doi.org/10.1155/2019/5452149

Gyan, E., Inkoom, S., & Amoako, G. (2020). Entrance skin dose assessment of selected computed radiography facilities in Ghana. *International Journal of Radiation Research, 18*(4), 817–823.

Maaruf, A., Gide, B. M., & Rufai, A. U. (2023). Determination of entrance surface dose for patients undergoing conventional chest X-ray examination at Radiology Department, Federal Teaching Hospital (FTH) Katsina. *UMYU Scientifica, 2*(1), 69–77. https://doi.org/10.56919/usci.1222.009

Mohammadain, K. E. M., da Rosa, L. A. R., Azevedo, A. C. P., Guebel, M. R. N., Boechat, M. C. B., & Habani, F. (2004). Dose evaluation for paediatric chest X-ray examinations in Brazil and Sudan: Low doses and reliable examinations can be achieved in developing countries. *Physics in Medicine and Biology*, *49*(6), 1017–1031. https://doi.org/10.1088/0031-9155/49/6/012

Nigeria Basic Ionizing Radiation Regulation (2003). NBIRR report, pariso T. C. (2008). The Dicom standard. The international journal of cardiac imaging. 11:171

Ofori, K., Gordon, S. W., Akrobortu, E., Ampene, A. A., & Darko, E. O. (2014). *Estimation of adult patient doses for selected X-ray diagnostic examinations. Journal of Radiation Research and Applied Sciences, 7*(4), 459–462. https://doi.org/10.1016/j.jrras.2014.08.003

Omojola, A. D., Agboje, A. A., Uche, K. B., Esu, E. O., Omojola, F. R., Anizor, M. I., & Robinson, E. D. (2021). Assessment of the impact of chest radiography on the breast of female patients in a medical facility in Asaba, Delta State: An evaluation of the lifetime cancer risk. *Journal of Radiological Studies, 6*(4), 20–30.

Omojola, A. D., Akpochafor, M. O., Adeneye, S. O., Akala, I. O., & Agboje, A. A. (2021). *Estimation of dose and cancer risk to newborn from chest X-ray in South-South Nigeria: A call for protocol optimization. Egyptian Journal of Radiology*

and Nuclear Medicine, 52, Article 69. https://doi.org/10.1186/s43055-021-00445-w

Rasuli, B., Mahmoud-Pashazadeh, A., Ghorbani, M., Juybari, R. T., & Naserpour, M. (2016). *Patient dose measurement in common medical X-ray examinations in Iran.* Journal of Applied Clinical Medical Physics, 17(1), 374–386. https://doi.org/10.1120/jacmp.v17i1.5860.

Rubai, S. S., Rahman, M. S., Purohit, S., Patwary, M. K. A., Meaze, A. K. M. H., & Mamun, A. A. (2018). *Measurements of entrance surface dose and effective dose of patients in diagnostic radiography. Biomedical Journal of Scientific and Technical Research, 12*(1), 1–5. https://doi.org/10.26717/BJSTR.2018.12.002186

Usikalu, M. R., Orosun, M. M., Akinpelu, A., Babarimisa, I. O., Arijaje, T. E., & Mohammed, A. U. (2024). *Environmental radioactivity monitoring and radiological impact assessment of Agbara Industrial Area, Ogun State, Nigeria.* Polytechnica, 7, Article 9. https://doi.org/10.1007/s41050-024-00052-4

Vatsa, M. A., Bello, I. A., Onuh, E., Garba, N. N., Kado, S., Ahmad, A. A., & Aminu, M. A. (2022). Assessment of entrance surface dose (ESD) in some routine X-ray examinations at the Faculty of Veterinary Medicine, Ahmadu Bello University, Zaria. *Bayero Journal of Pure and Applied Sciences, 13*(1), 87–91.

Wall, B. F., & Hart, D. (1997). Revised radiation doses for typical X-ray examinations: Report on a recent review of doses to patients from medical X-ray examinations in the UK by the NRPB. *British Journal of Radiology, 70*, 437–439.

Yacoob, H. Y., & Mohammed, H. A. (2017). *Assessment of patients' X-ray doses at three government hospitals in Duhok City lacking requirements of effective quality control.* Journal of Radiation Research and Applied Sciences, 10(3), 183–187. https://doi.org/10.1016/j.jrras.2017.04.005

Liu, X., Su, Q., Zhang, J., Chen, Y., Li, F., Xie, C., He, L., Liu, S., & Lv, Y. (2025). *Low-dose radiation exposure and health outcomes among healthcare workers: A multi-center prospective cohort study.* Journal of Health, Population and Nutrition, 44, Article 414. https://doi.org/10.1186/s41043-025-01133-5.

Najjar, R. (2023). Radiology's Ionising Radiation Paradox: Weighing the Indispensable Against the Detrimental in Medical Imaging. *Cureus, 15*(7), e41623.

John, M., & Mina, J. A. R. (2024). Medical Physics in Cancer Treatment: A Comprehensive Review of Innovations, Challenges, and Future Directions. *Radiation Science and Technology, 10*(2), 26–36.

Dudhe, S. S., Mishra, G., Parihar, P., Nimodia, D., & Kumari, A. (2024). *Radiation dose optimization in radiology: A comprehensive review of safeguarding patients and preserving image fidelity.* **Cureus, 16**(5), e60846. https://doi.org/10.7759/cureus.60846

Hassan, A., & Mraity, H. (2024). Patients' dosimetry during lumbar radiographic examination (Lat) in certain hospitals at Dhi Qar governorate, Iraq. *Journal of Kufa-Physics, 16*(1),

56–67. https://doi.org/10.31257/2018/JKP/2024/v16.i01.14419

Huang, S.-H., Huang, S.-R., & Chou, M.-C. (2024). Investigation of the relationship between body parameters and current–time product in kidney–ureter–bladder digital radiography. *Journal of Radiological Science, 49*(1), 39–44. https://doi.org/10.4103/jradiolsci.JRADIOLSCI-D-23-00035

Haider, U. H., Hussain, B., Shaheen, W., Iqbal, M., Sandhu, M. A., & Fatima, N. (2024). Comparison of directly and indirectly estimated entrance skin dose (ESD) for diagnostic radiation qualities (RQR, RQA and RQT) using water phantom and shadow-free diagnostic chamber (SFD). *Egyptian Journal of Radiology and Nuclear Medicine, 55*, 164. https://doi.org/10.1186/s43055-024-01337-5

Alomairy, N., Hadi, D., Al-Zaid, A., Fasikh, R., Arif, R., Al-Hazmi, R., Kharizy, A., Alyami, A., Hummdy, A., & Shubayr, N. (2023). Evaluation of the entrance surface doses (ESD) for common diagnostic X-ray examinations. *Journal of Radiation Research and Applied Sciences, 16*(4), 100754. https://doi.org/10.1016/j.jrras.2023.100754

Sidi, M., England, A., Mansur, U., Muhammad, Z., Garba, I., Zira, D., Abubakar, U., Abubakar, A. A., Ya'u, A., & Luntsi, G. (2024). *Radiation protection measures of the radiological facilities in Kano metropolis, Nigeria. West African Journal of Radiology, 29*(2), 118–124. https://doi.org/10.82235/wajr.vol29no2.49

Bamanga, A., Umaru, A., Musa, H. M., Mohammed, Y. M., Ali, A. M., Muhammed, I., Lawal, A., & Imam, Z. M. (2024). *Radiographers' knowledge, practice, and compliance with radiation protection measures in the radiology department. Annals of Basic and Medical Sciences, 4*, 377–382. https://doi.org/10.51658/ABMS.202331.6

Shamsi, K., Shabestani Monfared, A., Deevband, M. R., Mohsenzadeh, B., Ghorbani, M., Ebrahimnejad Gorji, K., & Niksirat, F. (2020). *Evaluation of effective dose and entrance skin dose in digital radiology. Polish Journal of Medical Physics and Engineering, 26*(2), 119–125. https://doi.org/10.2478/pjmpe-2020-0013