Evaluation of Radiation Exposure in Pediatric Patients for Minimizing Radiation-Induced Risks in a Tertiary Care Hospital

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ABSTRACT

Objectives: This study aims to evaluate the radiation dose received by pediatric patients (PPs) during lumbar-sacral spine (LS spine) imaging, review current imaging practices, identify potential risks, and promote radiation safety by adhering to pediatric-specific dose optimization protocols.

Methods: The entrance surface dose (ESD) was calculated using five different mathematical formulas, and direct measurements were obtained with a dose-area product (DAP) meter during LS spine imaging of PPs.

Results: The lowest mean ESD during lumbar spine imaging was observed in pediatric patients aged 1–5 years, measured at 0.25 mGy or 0.48 mGy·cm². Conversely, the highest mean ESD was recorded in the 10–15-year age group for the same projection, reaching 1.05 mGy or 0.89 mGy·cm². These values were derived from mathematical formulas and DAP meter measurements.

Conclusion: Radiation dose assessment should be performed for every medical imaging procedure using appropriate dosimetry equipment or validated methods. This is essential to optimize radiation exposure in pediatric patients while maintaining diagnostic image quality.

Keywords: *Entrance surface dose, Pediatric patients, Dose reference levels, DAP meter, Radiation dose optimization.*

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1. INTRODUCTION

Radiation, whether natural or manmade, travels through a medium as waves and particles. Medical professionals use X-rays, the most common form of artificial radiation, to diagnose and treat patients [1, 2]. In healthcare facilities, radiological examinations are the primary tool to diagnose disease in pediatric and adult patients. Pediatric patients (PPs) should not be viewed simply as "little adults" because of their significant body changes from birth to childhood. PPs are classified according to an age-based system: neonates (ages 0-28 days), infants (ages 28 days to 1 year), toddlers (ages 13 months to 2 years), children (ages 2 to 12 years), early adolescents (ages 12 to 18 years), and late adolescents (ages 19 to 21) [3,4]. PPs are more radiation-sensitive than adults and require more attention and care during radiological examinations due to their size and the developing stage of organs. The imaging region of the LS spine contains more radiosensitive organs, such as the ovaries, gonads, and small intestine. Therefore, radiation exposure to the LS spine must be evaluated to avoid stochastic effects of radiation, which say, "no dose is safe" [5]. However, the X-ray dose is very low in general radiography, but it transmits some amount of energy into the body that can harm crucial biological components, such as DNA, potentially leading to adverse effects [6, 7].

The International Commission on Radiological Protection (ICRP) has acknowledged the impact of this radiation and has recommended that all X-ray procedures maintain radiation doses within established limits [8, 9]. In conjunction with the ICRP, various international authorities have firmly emphasized three key core principles: justification, optimization, and dose limits. They also provided a set of reference doses for both adults and PPs [10, 11]. Radiation doses to the PPs vary with their physical parameters (age, height, weight, and body separation) and with the applied exposure factors (kVp, mAs, and distance). Therefore, to achieve the objective of this study, radiation exposure must be measured to assess the entrance surface dose (ESD) or dose reference levels (DRLs), while optimizing all PPs' specific parameters to minimize radiation-induced risks with better image quality [12, 13].

There are several techniques for assessing ESD, but a dose-area product meter (DAP meter) is used to quantify overall radiation exposure, considering the irradiated tissue area, and mathematical formulas are used to estimate radiation dose [14–16]. The use of mathematical formulas is the simplest way to calculate the radiation dose during the imaging. This sort of calculation relies on the applied exposure factors to yield an approximate result of ESD [17, 18]. In conventional radiography, computed radiography (CR), or digital radiography (DR), DAP meter values differ for the same medical imaging process [19, 20].

2. MATERIALS AND METHODS

This study was approved by the Office of the Ethics Committee, SMS Medical College and Attached Hospitals, Jaipur (Reference No: 731/MC/EC/2023) and conducted in the dedicated pediatric tertiary care hospital named *JK Lone Hospital*, during the period August 2023 to June 2024. Initially, the X-ray machine's (CR system) QA and QC procedure was performed according to AERB guidelines. The X-ray machine's tube output was measured at 0.93 mGy/m. The following formula was used for calculating ESD for PPs in terms of the entrance surface air kerma based on the tube output [21,22].

$$\mathbf{ESD = (O/P) \; x \; (kVp/80)^2 \; x \; (mAs) \; x \; (100/FSD)^2 \; x \; (BSF)}$$

The output (O/P) of the tube was measured along the axis of the beam, at a 100 cm distance from its focal point. The product of applied exposure time and tube current was used to determine the mAs value. The kVp represents the peak tube voltage used for each given investigation. The distance between the focus and the patient's surface is known as the focus-to-skin distance (FSD), and the backscatter factor (BSF) employed in this study was 1.35 [23,24].

This study was performed on 80 PPs under the age of 15 years, who were referred by a physician for LS spine imaging. The physical parameters of PPs (age, sex, weight) and the applied exposure factors were included in dosage calculation, estimation, and data accumulation. Radiation doses were assessed using two different methodologies

3. THEORETICAL METHOD

Here, ESD was computed using five formulas:

(i) Edmonds (1984): ESD (mGy) = $\frac{\mathbf{0.836*(kVp)^{1.74}*(mAs)}}{\mathbf{(SSD)^2}} * \left\{\frac{\mathbf{1}}{\mathbf{T}} + \mathbf{0.114}\right\}$

(ii) Arun Kumar et al. (1991): ESD (mGy) = $\frac{\mathbf{0.0129*(kVp)^{2.558}*(mAs)}}{\mathbf{(SSD)^2*T}}$

(iii) Chougule & Hussain (1993):

$$\text{ESD (mGy)} = \frac{\mathbf{0.107*(kVp)^{1.985}*(mAs)}}{\mathbf{P*(SSD)^2}} * \left(\frac{\mathbf{1}}{\mathbf{T}} + \mathbf{0.114}\right)$$

(iv) Pratik Kumar et al. (1996): ESD (mGy) = $\frac{\mathbf{0.00867*(kVp)^{2.79}*(mAs)}}{\mathbf{(SSD)^2*P*T}}$

(v) Chaun & Tsai (1999): ESD (mGy) = $\mathbf{0.2775} * \left(\frac{\mathbf{kVp}}{\mathbf{FSD}}\right)^{\mathbf{2}} \left(\frac{\mathbf{mAs}}{\mathbf{mm\ Al}}\right)$

Where:

ESD = Entrance surface dose,
kVp = Kilovolt peak
mAs = Milliampere seconds
P = 1(for 3-phase unit)
T=4 (Total tube filtration in mm Al)
SSD = Source to Skin Distance
FSD = Focus to Skin Distance
TSD = Tube to Skin Distance = 92 cm

4. EXPERIENTIAL METHOD

Simultaneously, the actual dose was estimated concurrently using a DAP meter, which measures the output of an X-ray tube with an energy range of 40-150 kVp. Therefore, a calibrated DAP meter (KERMAX-Plus SDP, model 120-210) was used in this study. It was capable of operating at temperatures from -20° to +50°, relative humidity 10 to 90% (without condensation), and pressure 500 to 1062 hPa. This DAP meter comprises an ionization chamber with its reader. First, the ionisation chamber was positioned beneath the X-ray tube collimator and connected to its reader, allowing measurements to be obtained within 1- 3 seconds. The DAP meter is independent of the X-ray source to surface distance (r); instead, it depends on applied KVp, mAs, or field size [25]. Measured doses were obtained in Gy*m^2 units, which were converted into Gy*cm^2 for data analysis and comparison [26]. The DAP meter readings were used to compute the mean, standard deviation (SD), minimum, maximum, median, and the first and third quartiles.

5. RESULT

In this study, the results were assessed using radiographic parameters and a combination of methods for dose calculation, including descriptive statistical analysis and qualitative evaluation. Data were analysed and presented using statistical indicators such as the first quartile, third quartile, standard deviation, mean, maximum, and minimum value. The radiographic and demographic details, including types of X-ray projection, patient age, weight, applied mAs, and kVp, are summarized in **Table 1**, along with their respective average ranges.

The mean ± SD values of ESD for each of the five mathematical methods are presented and compared in **Table 2**. According to the Arun Kumar et al (1991) formula, the 1-5-year age group's LS spine lateral projection showed the lowest mean ESD value of 0.25 mGy, while the 10–15-year age group's lumbar spine lateral view demonstrated the highest value of 1.05 mGy, calculated using Edmonds' (1984) formula. The mean ESD values were found to be greater for Edmon's formula across LS Spine AP/Lat X-ray projections, although radiation doses were found to be close to the formulas developed by Arun Kumar et al. (1991) and Chougule & Hussain (1993).

The DAP meter data are displayed concurrently in **Table 3**. The LS spine lateral projection for the age group 1 to 5 years exhibited the lowest third quartile value of 0.48 mGycm², while the LS spine lateral view for the age group 10 to 15 years showed the greatest value of 0.89 mGycm². **Table 4** illustrates that the DAP meter readings in the current study are significantly lower than in previous reported studies. **Figure 1** illustrates the comparison of the DAP meter results to other similar studies.

6. DISCUSSION

PPs are vulnerable to the radiation effects due to their developing stage, and extensive use of X-rays can damage DNA, resulting in mutations, long-term radiation-induced conditions, and cancer. In LS spine imaging, tissues with high rates of cellular proliferation—such as the bone marrow, gonads, and gastrointestinal tract—are especially vulnerable to the effects of radiation exposure. [27] Therefore, assessing the ESD is essential for ensuring the safety of patients undergoing medical imaging of the LS spine. In this study, the computation used many radiological and patient characteristics, excluding height, as shown in **Table 1**. In contrast to earlier studies that used limited formulas, often including Body Mass Index (BMI), this approach was more comprehensive [28,29].

Tube voltage settings of 60 to 80 kVp were advised by the European Commission for newborns aged 0 to 1 year and between 100 and 120 kVp for children aged 5 and up. Prior research recommended against utilizing tube voltages for pediatric patients lower than 60 kVp [30]. In this study, the average tube voltage for the 0–15 age group ranged from 55.60 to 63.16 kVp. Whereas earlier practices preferred high mA and low kV settings, recent advances in X-ray machine technology and technologist skills now enable better combinations of mA and kV to obtain satisfactory images with less radiation exposure [31].

Over the years, several theoretical formulas have been devised to estimate ESD, each employing various factors to increase accuracy. We compared the data for all five mathematical formulas and found that Edmonds'(1984) formula had the greatest mean ESD across all X-ray projections, whereas Arun Kumar et al. (1991) had the lowest. Simpler formulas like Edmonds (1984) are easier to apply but less accurate across patient anatomy [32]. Complex models like Chaun & Tsai (1999) and Pratik Kumar et al. (1996) are more accurate but less feasible for clinical use. Chougule & Hussain (1993) worked for certain transportable radiography settings but lacked patient-specific considerations. Arun Kumar et al. (1991) balance accuracy and usability by including patient characteristics [33,34]. Overall, these formulas provide quick, cost-free ESD estimation without specialized equipment, with the choice depending on clinical needs and available data [35].

The ESD in PPs was calculated simultaneously using a DAP meter, without any changes to radiological or patient-related parameters. The calculation considered the fact that the formula units differ from those of the DAP meter, which measures both the quantity of radiation and the exposed area. This approach allowed for a rapid and accurate estimation of ESD [36]. The minimum third quartile value recorded was 0.48 mGycm² for the LS spine lateral projection in the 1-5-year age group, while the maximum value of 0.89 mGycm² was noted for the lumbar spine lateral view in the 10–15-year age group. The DAP meter data from this study were compared with findings from other relevant studies. X-ray imaging of LS Spine-AP, LS Spine- showed significantly lower DRL values compared to those reported in four studies: UK (2009), India (2011), USA (2012), and Germany (2019). Variations in results can be attributed to factors such as the number of patients, applied kVp, mAs, collimation, film-to-source distance (FSD), type of X-ray machine, and the techniques employed by radiation technologists [37–40].

The results of this study are consistent with the existing literature. This type of research aids in optimizing radiation doses for patients without compromising image quality. The value of local diagnostic reference levels (LDRLs) can be reduced through periodic quality assurance (QA) and quality control (QC) tests of machines as needed, training radiation technologists by offering refresher courses, adhering to diagnostic reference levels (DRLs) and guidelines, utilizing appropriate immobilization devices, and managing the working hours of radiation technologists [41].

7. CONCLUSION

This type of study approach facilitates the quick evaluation of ESD through mathematical formulas, but results are varied due to the structure of the formula. However, the DAP meter is considered a more reliable tool for accurately measuring ESD. Therefore, DAP meter readings are necessary to assess ESD and establish DRLs for a tertiary care hospital to achieve better-quality images with minimum radiation-induced risk to PPs.

ABBREVIATIONS

PPs	Pediatric Patients
ICRP	International Commission on Radiation Protection
QA	Quality Assurance
QC	Quality Control
ESD	Entrance Surface Dose
DRLs	Dose Reference Levels
LDLs	Local Dose Reference Levels
DAP	Dose Area Product
TLD	Thermoluminescence Dosimeter
CR	Computed Radiography
DR	Digital Radiography
AERB	Atomic Energy Regulatory Board
KVp	Peak kilovolts
mAs	Milliampere-seconds
FSD	Film to Source Distance
NRPB	National Radiation Protection Board
BSF	Backscatter factor
AP	Anterior to Posterior
PA	Posterior to Anterior
FPA	Flat Plate Abdomen
KUB	Kidney Ureter Bladder
FSD	Focus to Skin Distance

Ethical approval:
This was an observational study, and ethical approval was obtained from the Office of the Ethics Committee, SMS Medical College and Attached Hospitals, Jaipur (Reference No: 731/MC/EC/2023).

Availability of data and materials:
The data supporting the findings of the article are available within the article.

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Conflict of Interest Statement:
None

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REFERENCE

[1] Thorne, M. C. (2003). Background radiation: Natural and man-made. *Journal of Radiological Protection, 23*(1), 29–42. https://doi.org/10.1088/0952-4746/23/1/302

[2] Scatliff, J. H., & Morris, P. J. (2014). From Roentgen to magnetic resonance imaging: The history of medical imaging. *North Carolina Medical Journal, 75*(2), 111–113. https://doi.org/10.18043/ncm.75.2.111

[3] Clark, R., Locke, M., & Bialocerkowski, A. (2015). Paediatric terminology in the Australian health and health-education context: A systematic review. *Developmental Medicine & Child Neurology, 57*(11), 1011–1018. https://doi.org/10.1111/dmcn.12803

[4] Althammer, A., Prückner, S., Gehring, G. C., Lieftüchter, V., Trentzsch, H., & Hoffmann, F. (2023). Systematic review of age brackets in pediatric emergency medicine literature and the development of a universal age classification for pediatric emergency patients—The Munich Age Classification System (MACS). *BMC Emergency Medicine, 23*(1), Article 77. https://doi.org/10.1186/s12873-023-00851-5

[5] Simpson, A. K., Whang, P. G., Jonisch, A., Haims, A., & Grauer, J. N. (2008). The radiation exposure associated with cervical and lumbar spine radiographs. *Journal of Spinal Disorders & Techniques, 21*(6), 409–412. https://doi.org/10.1097/BSD.0b013e3181568656

[6] Van Dyk, J., & Chougule, A. (2022). *True tales of medical physics: Insights into a life-saving specialty* (pp. 335–356). Springer Nature. https://doi.org/10.1007/978-3-030-91724-1

[7] Wilkinson, B., Hill, M. A., & Parsons, J. L. (2023). The cellular response to complex DNA damage induced by ionising radiation. *International Journal of Molecular Sciences, 24*(5), Article 4920. https://doi.org/10.3390/ijms24054920

[8] Clement, C., Rühm, W., Harrison, J., Applegate, K., Cool, D., Larsson, C. M., Cousins, C., Lochard, J., Bouffler, S., Cho, K., Kai, M., Laurier, D., Liu, S., & Romanov, S. (2021). Keeping the ICRP recommendations fit for purpose. *Journal of Radiological Protection, 41*(4). https://doi.org/10.1088/1361-6498/ac1611

[9] Vañó, E., Miller, D. L., Martin, C. J., Rehani, M. M., Kang, K., Rosenstein, M., Ortiz-López, P., Mattsson, S., Padovani, R., & Rogers, A. (2017). ICRP Publication 135: Diagnostic reference levels in medical imaging. *Annals of the ICRP, 46*(1), 1–144. https://doi.org/10.1177/0146645317717209

[10] Rizk, C., Fares, G., Vanhavere, F., Saliba, Z., & Farah, J. (2020). Diagnostic reference levels, deterministic and stochastic risks in pediatric interventional cardiology procedures. *Health Physics, 118*(1), 85–95. https://doi.org/10.1097/HP.0000000000001114

[11] Malone, J. (2020). X-rays for medical imaging: Radiation protection, governance and ethics over 125 years. *Physica Medica, 79*, 47–64. https://doi.org/10.1016/j.ejmp.2020.09.012

[12] Båth, M., Hoeschen, C., Mattsson, S., & Månsson, L. G. (2016). Optimisation in X-ray and molecular imaging 2015. *Radiation Protection Dosimetry, 169*(1–4), 1. https://doi.org/10.1093/rpd/ncw117

[13] Junda, M., Muller, H., & Friedrich-Nel, H. (2021). Local diagnostic reference levels for routine chest X-ray examinations at a public sector hospital in central South Africa. *Health SA Gesondheid, 26*, Article 1622. https://doi.org/10.4102/hsag.v26i0.1622

[14] Metaxas, V. I., Messaris, G. A., Lekatou, A. N., Petsas, T. G., & Panayiotakis, G. S. (2019). Patient doses in common diagnostic X-ray examinations. *Radiation Protection Dosimetry, 184*(1), 12–27. https://doi.org/10.1093/rpd/ncy169

[15] Davoodi, R., Eydian, M. R., Karampour, H., Nassarpour, M., Rezazadeh-Farokh, R., Maraei, A., & Chavideh, M. (2020). Application of dose area product (DAP) to estimate entrance surface dose (ESD) in pediatric chest X-rays. *Modern Health Science, 3*(2), Article 1. https://doi.org/10.30560/mhs.v3n2p1

[16] Abdallah, Y. (2021). Measurement of entrance skin dose in radiographic examinations of pediatric patients. *Current Medical Imaging, 17*(11), 1385–1389. https://doi.org/10.2174/1573405617666210628162238

[17] Regulla, D. F., & Eder, H. (2005). Patient exposure in medical X-ray imaging in Europe. *Radiation Protection Dosimetry, 114*(1–3), 11–25. https://doi.org/10.1093/rpd/nch538

[18] Alghou, A. (2017). Mathematical evaluation of entrance surface dose (ESD) for patients examined by diagnostic X-rays. *Open Access Journal of Science, 1*(1). https://doi.org/10.15406/oajs.2017.01.00003

[19] Willis, C. E. (2007). Optimization of dose and image quality for computed radiography and digital radiography. *Journal of Digital Imaging, 20*(1), 1–3. https://doi.org/10.1007/s10278-007-1067-4

[20] Martin, C. J. (2008). Radiation dosimetry for diagnostic medical exposures. *Radiation Protection Dosimetry, 128*(4), 389–412. https://doi.org/10.1093/rpd/ncm495

[21] Suliman, I. I., & Elshiekh, E. H. (2008). Radiation doses from some common paediatric X-ray examinations in Sudan. *Radiation Protection Dosimetry, 132*(1), 64–72. https://doi.org/10.1093/rpd/ncn232

[22] Theocharopoulos, N., Perisinakis, K., Damilakis, J., Varveris, H., & Gourtsoyiannis, N. (2002). Comparison of four methods for assessing patient effective dose from radiological examinations. *Medical Physics, 29*(9), 2070–2079. https://doi.org/10.1118/1.1500769

[23] Zewdu, M., Kadir, E., & Berhane, M. (2017). Assessment of pediatric radiation dose from routine X-ray examination at Jimma University Hospital, Southwest Ethiopia. *Ethiopian Journal of Health Sciences, 27*(5), 481–490. https://doi.org/10.4314/ejhs.v27i5.6

[24] Teferi, S., & Zewdeneh, D. (2020). Variation of pediatric doses undergoing digital and computed radiography examination in Addis Ababa, Ethiopia. *Ethiopian Journal of Health Sciences, 30*(2), 269–276. https://doi.org/10.4314/ejhs.v30i2.15

[25] Park, H., Yoon, Y., Kim, J., Kim, J., Jeong, H., Tanaka, N., & Morishita, J. (2020). Use of clinical exposure index and deviation index based on national diagnostic reference level as dose-optimization tools for general radiography in Korea. *Radiation Protection Dosimetry*. https://doi.org/10.1093/rpd/ncaa185

[26] Kisielewicz, K., Truszkiewicz, A., Wach, S., & Wasilewska-Radwańska, M. (2011). Evaluation of dose area product vs. patient dose in diagnostic X-ray units. *Physica Medica, 27*(2), 117–120. https://doi.org/10.1016/j.ejmp.2010.07.001

[27] Sawyer, J. R. (2021). Radiation reduction strategies in pediatric orthopaedics. *Journal of Pediatric Orthopaedics, 41*(Suppl 1), S75–S79. https://doi.org/10.1097/BPO.0000000000001822

[28] Efthymiou, F. O., Metaxas, V. I., Dimitroukas, C. P., Kakkos, S. K., Moulakakis, K. G., Belavgenis, A. C., & Panayiotakis, G. S. (2023). BMI-based organ doses in endovascular aneurysm repair interventions utilising Monte Carlo simulation. *Applied Radiation and Isotopes, 195*, Article 110740. https://doi.org/10.1016/j.apradiso.2023.110740

[29] Heymsfield, S. B., Sorkin, J. D., Thomas, D. M., Yang, S., Heo, M., McCarthy, C., Brown, J., & Pietrobelli, A. (2025). Weight/height^2: Mathematical overview of the world's most widely used adiposity index. *Obesity Reviews, 26*(1), e13842. https://doi.org/10.1111/obr.13842

[30] Aboul Hamad, M. S., Attalla, E. M., Amer, H. H., & Fathy, M. M. (2023). Assessment of diagnostic reference levels for paediatric cardiac computed tomography in accordance with European guidelines. *Radiation and Environmental Biophysics, 62*(3), 331–338. https://doi.org/10.1007/s00411-023-01031-6

[31] Pengpan, T., Rattanarungruangchai, N., Dechjaithat, J., Panthim, P., Siricharuwong, P., & Prapan, A. (2022). Optimization of image quality and organ absorbed dose for pediatric chest X-ray examination: In-house developed chest phantom study. *Radiology Research and Practice, 2022*, Article 3482458. https://doi.org/10.1155/2022/3482458

[32] Edmonds, I. R. (1984). Calculation of patient skin dose from diagnostic X-ray procedures. *British Journal of Radiology, 57*(680), 733–734. https://doi.org/10.1259/0007-1285-57-680-733

[33] Tung, C. J., & Tsai, H. Y. (1999). Evaluations of gonad and fetal doses for diagnostic radiology. *Proceedings of the National Science Council, Republic of China, Part B, 23*(3), 107–113.

[34] Chougule, A., & Hussain, S. (1993). Verification of an empirical formula for estimation of skin exposure during radiography. *Indian Radiology and Imaging, 3*, 49–50.

[35] Seydou, H., & Kawu, A. A. (2020). Assessment of dose for chest X-ray examination at the State Specialist Hospital, Gombe (SSHG), and the Federal Teaching Hospital. *BIMA Journal, 4*(1), 268–280.

[36] Nickoloff, E. L., Lu, Z. F., Dutta, A. K., & So, J. C. (2008). Radiation dose descriptors: BERT, COD, DAP, and other strange creatures. *Radiographics, 28*(5), 1439–1450. https://doi.org/10.1148/rg.285075748

[37] Hart, D., Hillier, M. C., & Wall, B. F. (2009). National reference doses for common radiographic, fluoroscopic and dental X-ray examinations in the UK. *British Journal of Radiology, 82*(973), 1–12. https://doi.org/10.1259/bjr/12568539

[38] Sonawane, A. U., Kumar, J. V. S., Singh, M., & Pradhan, A. S. (2011). Suggested diagnostic reference levels for paediatric X-ray examinations in India. *Radiation Protection Dosimetry, 147*(3), 423–428. https://doi.org/10.1093/rpd/ncq458

[39] Schegerer, A., Loose, R., Heuser, L. J., & Brix, G. (2019). Diagnostic reference levels for diagnostic and interventional X-ray procedures in Germany: Update and handling. *RöFo, 191*(8), 739–751. https://doi.org/10.1055/a-0824-7603

[40] National Council on Radiation Protection and Measurements. (2012). *Reference levels and achievable doses in medical and dental imaging* (NCRP Report No. 172).

[41] Paulo, G. (2021). The role of pediatric radiologists and radiographers: A different future from the past. *Pediatric Radiology, 51*(4), 529–531. https://doi.org/10.1007/s00247-019-04597-w

Figure Legends:

Figure 1:

The bar graph compares the DRL values from this study to those from the UK (Hart D. et al., 2009), India (Sonawane A. U. et al., 2011), the USA (Brink J.A. et al., 2012), and Germany (Schegerer, A. et al., 2019). In such studies, the DRL values are typically found lower.

Carcinogenesis

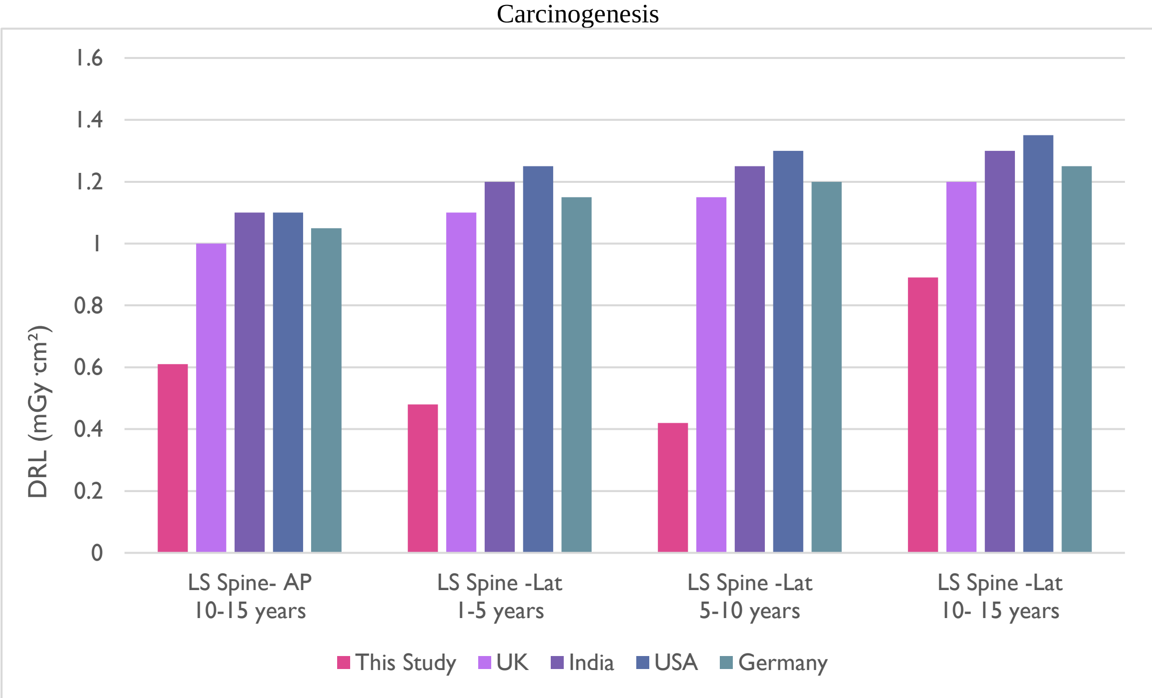

Table Legends:

Table 1: Explain radiological and patient parameters, along with their means and ranges. Radiological parameters are used to calculate dose, and patient parameters are used to calculate BMI and body separation.

S. No	Projection	Number	Age (year)	Sex	Patient Weight (Kg)	mAs	Total Voltage (kVp)
	L S Spine – AP	20	13.67 (10-15 years)	8 (F), 12 (M)	27.083 (18-35)	18.16 (16-25)	63.16 (58-68)
	L S Spine – Lat	60	7.64 (1-15 years)	25 (F), 35 (M)	17.5 (5-36)	18 (13-25)	63.09 (58-70)

Table 2: Explain a comparison of the mean±SD values of ESD across all five mathematical formulas.

S. No.	Projection	Number	Age (Year)	Edmonds (1984)	Arun Kumar et al (1991)	Chougule & Hussain (1993)	Pratik Kumar et al (1996)	Chaun & Tsai (1999)
1.	L S spine – AP	20	10-15	0.89±0.23	0.28±0.08	0.31±0.09	0.50±0.15	0.26±0.16
2.	L S spine – Lat	20	1-5	0.81±0.14	0.25±0.05	0.28±0.05	0.43±0.09	0.60±0.09
		20	5-10	0.83±0.15	0.26±0.05	0.29±0.05	0.45±0.09	0.54±0.10
		20	10-15	1.05±0.36	0.35±0.02	0.37±0.13	0.62±0.23	0.55±0.25

Values are presented as mean ± SD, and sample sizes (n) = 20

Table 3: Explain the mean ± SD, minimum, first quartile, third quartile, maximum, median, and maximum to minimum ratio of the DAP meter values.

S. No.	Projection	Age (Year)	Mean ± SD	Min	1st Quartile	3rd Quartile	Max	Median	Max/Min
1.	L S spine – AP	10-15	0.44±0.04	0.27	0.27	0.61	0.67	0.44	2.50
2.	L S spine – Lat	1-5	0.36±0.01	0.26	0.26	0.48	0.51	0.34	1.97
		5-10	0.37±0.08	0.30	0.31	0.42	0.53	0.33	1.75
		10-15	0.79±0.06	0.68	0.68	0.89	0.89	0.79	1.31

Values are presented as mean ± SD, and sample sizes (n) = 20

Table 4: Explain the results of this study are closely aligned with the DRL values reported in earlier studies.

S. No.	Projection	Age (Year)	This Study	UK[a]	India[b]	USA[c]	Germany[d]
1.	L S spine - AP	10-15	0.61	1.00	1.10	1.10	1.05
2.	L S spine - Lat	1-5	0.48	1.10	1.20	1.25	1.15
		5-10	0.42	1.15	1.25	1.30	1.20
		10-15	0.89	1.20	1.30	1.35	1.25

a Hart D. et al., 2009; b Sonawane A. U. et al., 2011; c Brink J.A. et al., 2012; d Schegerer, A. et al., 2019