

Establishing of a National Diagnostic Reference Level for Radiation Dose in Digital Paediatric Pelvic X-Rays in Jordan: A Multicenter Retrospective Study

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Background: Paediatric pelvic X-rays are essential for diagnosing injuries and developmental abnormalities but pose radiation risks to sensitive children. Dose Reference Levels (DRLs) play a critical role in optimising radiographic procedures, ensuring both safety and high-quality imaging.

Objective: This research aimed to establish a National Dose Reference Level (NDRL) for digital paediatric pelvic X-rays in Jordan to optimise radiation doses, improve diagnostic accuracy, and minimise risks.

Methods: A Multicenter retrospective analysis was performed on paediatric Anterior-Posterior (AP) digital pelvic X-rays from various 12 Jordanian healthcare institutions. Parameters including Kilovoltage peak (kVp), milli Ampere second (mAs), and Focal to Skin Distance (FSD) were collected. Entrance Surface Dose (ESD) was indirectly calculated following international guidelines.

Results: The study analysed 1,674 paediatric pelvic X-rays, finding a mean ESD of 0.69 milli-Gray (mGy). The 75th percentile ESD, or (DRL), was 0.612 mGy overall, with age-specific DRLs of 0.265 mGy (0 to <1 year), 0.382 mGy (1 to <5 years), 0.704 mGy (5 to <10 years), and 0.995 mGy (10 to ≤15 years).

Conclusion: The study revealed age-dependent variations and notable disparities in radiation doses among various healthcare institutions in Jordan. Establishing the NDRL of 0.612 mGy provides a benchmark for dose optimisation and aligns Jordan's practices with international standards. The findings can guide national radiation protection policies and clinical guidelines, enhance paediatric imaging practices, and minimise unnecessary radiation exposure.

Keywords: radiation safety, paediatric radiography, dose reference levels, DRLs, dose optimisation, medical imaging, Jordan

Introduction

Medical imaging (MI) is vital in modern healthcare, providing essential diagnostic information across a wide range of conditions.¹ Many MI procedures utilise ionising radiation, including conventional radiography, which remains prevalent in developing countries due to its affordability and accessibility.^{2,3} Notably, radiologic medical procedures are the main cause of radiation exposure for the public in numerous countries and are the largest contributor to the applications of ionising radiation in the medical domain.^{3,4} The evolution of X-ray technology and increasing examination complexities have led to higher patient radiation doses.³ Diagnostic X-ray exams account approximately for about 80% of the general population's radiation exposure.⁵

Although ionising radiation facilitates accurate diagnoses, it concurrently introduces considerable risks, especially for vulnerable populations like paediatric patients.⁶ Paediatric pelvic radiography is routinely employed for the assessment of traumatic and congenital injuries, in addition to developmental abnormalities. However, the radiosensitivity of children's pelvic regions necessitates distinct challenges for radiation management.⁸ Female paediatric patients exhibit particular

vulnerability, given the anatomical location of their ovaries within the radiation field, which leads to a comparatively greater exposure than that experienced by males.⁹

The use of radiation shielding in paediatric imaging underscores the ongoing debate between protecting patients and maintaining diagnostic image quality. Evidence-based protocols are necessary to reconcile these objectives.⁶

Establishing DRLs represents an important benchmark for optimising radiation doses in medical imaging procedures, helping identify and reduce unnecessarily high exposure while maintaining diagnostic quality.^{7,8} The International Commission on Radiological Protection (ICRP) and other international organisations advocate for DRLs to standardise radiation doses and identify unnecessarily high exposures while maintaining diagnostic efficacy.⁹ ESD is recognised as the primary used for basic radiography evaluations due to its ease of measurement, comparability with international studies, and strong correlation with effective dose.¹⁰

Research from the Middle East and North Africa (MENA) region reveals significant discrepancies in reported paediatric DRLs, stemming from variations in imaging techniques, equipment, and procedural protocols. Reported DRLs for paediatric pelvic X-rays range from 1.88 mGy in Iraq¹¹ to 0.63 mGy in Saudi Arabia,¹² highlighting the need for standardised national guidelines to ensure paediatric radiation safety and dose optimisation. Iran documented a DRL of 0.59 mGy for children's pelvis X-rays, reflecting discrepancies even within the region.¹³

Global variations in DRLs are evident: In Korea, the DRL for pelvic AP projection in 10-year-old patients was set at 1.0 mGy, with a reported range of 0.1 to 5.26 mGy.¹⁴ In Kenya, values demonstrated variation from 0.1 mGy for toddlers under one year to 0.36 mGy for children aged 10 to 15 years.¹⁵ Portugal's DRLs ranged from 0.098 mGy for infants to 0.573 mGy for older adolescents,¹⁶ while Ethiopia recorded values of 1.05 mGy for younger children and 25.03 mGy for older paediatric cohorts.¹⁷ These inconsistencies underscore the necessity for customised national guidelines to ensure paediatric patients' safety and dose optimisation in paediatric imaging.

Despite the significance of DRLs, Jordan lacks NDRLs for paediatric pelvic X-rays. This deficiency may contribute to substantial variances in radiation doses among healthcare facilities raising concerns about patient overexposure and associated radiation risks, as well as underexposure that could compromise diagnostic accuracy.¹⁸

This study aims to establish NDRLs for paediatric pelvic X-rays in Jordan, investigating variations caused by imaging equipment, procedures, and operator training.

In this study, age-based DRLs were selected in preference to weight or height, primarily for their clinical practicality and consistency with global dose assessment procedures. This age-based grouping facilitates the implementation of DRLs in clinical settings, particularly where weight or height data might be inconsistent or unavailable across various institutions.¹⁹ Moreover, age groups more precisely reflect skeletal and tissue development, establishing them as a reliable metric for dose optimisation in paediatric imaging.²⁰

The establishment of NDRLs in Jordan is anticipated to significantly impact policy and clinical practice. It will facilitate the reduction of excessive radiation exposure by providing standardised dose benchmarks, thereby ensuring diagnostic efficacy. The findings will align of Jordan's radiology practices with international standards, improving radiation safety and advancing best practices in paediatric imaging. The implementation of NDRLs can inform national healthcare policies, directing future initiatives to enhance dose monitoring, training, and equipment optimisation within Jordanian medical institutions.¹⁷ All abbreviations used throughout this manuscript are defined in [Supplementary Material Table S1](#).

Methods

Study Design

This multicenter retrospective study aimed to establish an NDRL for digital paediatric pelvic X-rays in Jordan. The inclusion criteria for this study comprised paediatric patients 15 years old and below who underwent AP digital pelvic X-ray examinations from June 2022 to June 2023 within any of the participating healthcare institutions, provided their imaging records were complete with all essential exposure parameters such as kVp, mAs, and FSD. Patients were excluded if they were over 15 years of age, had imaging performed for non-pelvic conditions, had incomplete exposure data, were imaged outside the participating centers, or if their images were of poor quality or contained technical errors.

The study was conducted across 12 healthcare institutions in Jordan, which were strategically chosen to encompass regional variation and differing capacities of healthcare service provision. This cohort included six governmental hospitals (MOH), one university hospital (UNIV), three Royal Medical Services hospitals (RMSH), and two private hospitals (PRIV).

Equipment and Quality Control Measures

The study used a variety of digital X-ray machines, including Digital Radiography (DR) and Computed Radiography (CR) systems, from different manufacturers and models, as detailed in [Supplementary Table S2](#).

The retrospective nature of the study precluded the application of direct quality control (QC) procedures. However, the large sample size and the inclusion of several institutions enhanced the representativeness of the findings for paediatric pelvic X-rays performed in Jordan.

Sample Size and Technique

The sample population was sourced from the Jordan Bureau of Statistics. The sample size was calculated using Daniel's formula (1).

$$n = \frac{Z^2 P(1 - P)}{d^2} \quad (1)$$

where:

n = sample size,

Z = the level of confidence of 95%, which is *conventional*; the Z value is 1.96

P = expected prevalence or proportion (in proportion of one; if 20%, $P = 0.2$)

d = precision (5%, $d = 0.05$).

An initial sample size of 346 was derived; however, to address concerns regarding missing data and to achieve greater statistical power, the final sample size was augmented to 1,674. This expansion enabled precise evaluations of radiation exposure in paediatric pelvic X-rays, contributing to the formulation of a NDRL in Jordan. To guarantee proportional representation, institutions were selected using a stratified random method, categorised by healthcare facility type (MOH, UNIV, RMS, PRIV) and geographic location.

To minimise potential bias from missing data, available-case analysis was performed, allowing for the inclusion of all available information without discarding complete cases. Additionally, missing exposure parameters were retrieved from Digital Imaging and Communications in Medicine (DICOM) metadata and manually verified against hospital records, thereby reducing data loss.

Data Collection and ESD Calculation

DICOM tags were used to extract the data from the X-ray images, or the patient's age at the time of the request, gender, and exposure factors like kVp, mA, exposure time, and FSD were collected manually through the electronic healthcare medical system.

Paediatric patients, from newborn to 15 years, were categorised into four non-overlapping age groups: 0 to <1 year, 1 to <5 years, 5 to <10 years, and 10 to ≤15 years. This classification was based on developmental stages, institutional imaging protocols, and the Jordanian Bureau of Statistics' demographic standards. Age-based grouping was chosen over weight or height for its practicality in clinical environments, alignment with international guidelines (eg, ICRP and the European Commission), and strong correlation with skeletal maturation, making it a reliable criterion for dose assessment in paediatric X-ray imaging.²¹ Additionally, this approach ensures comparability with local and regional dose surveys and reflects actual imaging practices across Jordan.

The DRL paediatric pelvic radiography was determined based on European Commission and ICRP guidelines.^{9,22} The ESD was computed utilising the exposure parameters documented for each patient. Hospitals where FSD data could not be collected due to time constraints were classified as having no data availability. However, all participating institutions included in the study routinely collect FSD from imaging services. The ESD was calculated using the following equation 2:²³

$$ESD (mGy) = \frac{c (kVp)}{(FSD)^2} * (mA/mm. Al) \quad (2)$$

ESD = skin dose in mGy,

c = a constant with a value of 0.2775

kVp =Kilo volts peak

FSD = Focus skin distance in m

mA = Milliampere

mm.Al = the total filtration Aluminum in mm

All calculations were automated in Excel, allowing for efficient computation of patient-specific radiation doses.

Data Analysis

Continuous variables were presented as mean \pm standard deviation (SD), and categorical variables were illustrated through counts and corresponding percentages. Following the ICRP 135 recommendations, the NDRLs were determined as the 75th percentile (third quartile) of the mean distribution in the sample.⁹ The Shapiro–Wilk test was employed to evaluate the normality of continuous variables, ascertaining if the data satisfied the prerequisites for parametric tests. Since the study included a large sample size, analysis of variance (ANOVA) was used to examine potential differences in ESD across different groups or categories, with statistical significance established at $p < 0.05$.

The pairwise deletion method was used to deal with missing data, ensuring that available data were preserved for analysis while avoiding the exclusion of entire cases. All data analyses were performed using IBM SPSS software, version 26.0.

Ethical Consideration

Ethical approval for the study was obtained from the Institutional Review Board (IRB) at Jordan University of Science and Technology, with approval granted on 1/11/2023 No. 34/164/2023.

Results

Demographic Profile

The study included a total of 1,674 paediatric patients with a virtually balanced gender distribution: 49.6% (n=831) female and 50.4% (n=843) male. The age distribution showed a relatively balanced profile, with a greater proportion of younger patients. The 0– <1 year cohort constituted 28.9% (n=483), succeeded by the 1– <5 year cohort at 27.7% (n=463), the 5– <10 year cohort at 22.5% (n=376), and the 10 – \leq 15 year cohort at 21.0% (n=352). The detailed demographic distribution across healthcare institutions is presented in [Table 1](#).

Table 1 Descriptive Statistics and ANOVA Results for ESD* by Age Groups

Age-Groups	ESD (mGy)**				
	N	Percentage	Mean	Q3/NDRL [†]	P-value
0 to <1Year	483	28.9%	0.34 \pm 0.53	0.2653	0.001
1 to <5Years	463	27.7%	0.42 \pm 0.64	0.3822	
5 to <10Years	376	22.5%	0.74 \pm 1.29	0.7038	
10 to \leq 15Years	352	21.0%	1.46 \pm 3.67	0.9952	
Overall	1674	100%	0.69 \pm 1.89	0.6118	

Notes: *Entrance Surface Dose; **Milli-Gray; [†]Third Quartile/National Diagnostic Reference Level.

Table 2 kVp, mAs, and FSD by Age Group

Age-Groups	kVp*		mAs**		FSD (cm) [†]	
	Mean ±SD [‡]	Min-Max	Mean ±SD	Min-Max	Mean ±SD	Min-Max
0 to <1Year	65.9±8.9	48.0–85.0	3.958±3.39	0.650–26.49	93.80±1.74	82.00–97.0
1 to <5Years	66.5±8.0	48.0–90.0	4.769±6.35	1.000–69.85	89.38±1.48	83.00–95.0
5 to <10Years	70.0±7.3	50.0–90.0	6.713±8.66	0.680–69.02	85.81±1.45	82.00–90.0
10 to ≤15Years	72.7±7.7	50.0–102.0	10.236±16.07	0.820–125.60	82.86±2.01	80.00–90.0
Overall	68.41 ± 8.48		6.12 ± 9.53		88.48 ± 4.41	

Notes: *Kilovoltage peak; **milliamperere-seconds; [†]Focus-to-Skin Distance; [‡]Standard Deviation.

Technical Parameters

Preliminary assessment of data distribution was performed using the Shapiro–Wilk test to inform the selection of appropriate descriptive statistics for the technical parameters. The results showed statistically significant deviations from normality for all variables: kVp ($p < 0.001$), mAs ($p < 0.001$), FSD ($p < 0.001$), and ESD ($p < 0.001$). Although kVp and FSD showed near-normal distribution visually, the statistical tests indicated non-normality. Accordingly, descriptive statistics are presented using mean \pm SD for consistency and interpretability.

The average kVp was 68.41 ± 8.48 , the average mAs was 6.12 ± 9.53 , the average FSD was $88.48 \text{ cm} \pm 4.41$, and the average ESD was $0.69 \text{ mGy} \pm 1.89$. As shown in [Table 2](#), exposure factors such as kVp, mAs, and FSD vary across paediatric age groups. These variations reflect clinical practice adjustments based on patient size and imaging needs. [Table 2](#) also presents the variations in mean kVp, mAs, and FSD values among different age groups, including the overall means. The overall mean and SD for ESD are presented in [Table 1](#).

Diagnostic Reference Level

The evaluation of ESD across different age groups in Jordan demonstrated inconsistencies related to differences in patient size and imaging protocols. The mean ESD demonstrated an increasing trend with age, beginning at 0.35 mGy for the $0 - <1$ year cohort (SD 0.53 mGy) and rising to 1.46 mGy in the $10 - \leq 15$ -year cohort (SD 3.67 mGy). The youngest group exhibited minimal variability, whereas the $10-15$ -year cohort demonstrated the greatest variability, with Q3/DRL values attaining 0.995 mGy .

The ANOVA conducted on age groups and ESD revealed statistically significant differences in mean ESD across the age groups (P -value = 0.001), as shown in [Table 1](#). This analysis was essential in assessing whether radiation dose levels differed significantly with patient age, thereby ensuring the appropriate establishment of age-based DRLs. These findings underscore the importance of modifying exposure parameters according to patient age to enhance radiation safety and reduce unnecessary exposure in paediatric imaging.

Hospital-Specific ESD Analysis

[Table 3](#) shows notable differences in ESD values amongst hospitals. Hospitals like UNIV1 and PRIV2 recorded the lowest mean ESDs, indicating compliance with dose optimisation protocols. In contrast, MOH5 and RMSH2 demonstrated the highest mean ESDs, with MOH5 showing the widest range ($0.413-55.260 \text{ mGy}$), reflecting significant variability in imaging practices that requires further investigation.

Table 3 Demographic and Dose Distribution by Hospital

Hospitals	ESD** (mGy) [#]							
	N	%	Mean	SD	Minimum	Maximum	Q1 [¶]	Q3/DRL [*]
RMSHI*	319	19.1%	0.2497	0.1469	0.073	1.2084	0.172	0.268
MOHI [†]	180	10.8%	0.8637	1.1205	0.088	7.6035	0.182	1.141
UNIVHI [‡]	157	9.4%	0.1642	0.0835	0.052	0.4532	0.109	0.189
PRIVI [§]	133	7.9%	0.3017	0.2543	0.060	0.8290	0.103	0.419
RMSH2	124	7.4%	2.4592	2.4553	0.281	13.6572	0.953	2.59
MoH2	121	7.2%	0.570	0.618	0.095	3.407	0.230	0.54
PRIV2	118	7.0%	0.226	0.345	0.095	2.858	0.112	0.15
MoH3	108	6.5%	0.436	0.253	0.098	1.509	0.253	0.58
MoH4	108	6.5%	0.367	0.233	0.079	1.309	0.188	0.61
RMSH3	104	6.2%	0.180	0.128	0.042	0.891	0.110	0.22
MoH5	100	6.0%	3.076	6.175	0.413	55.260	0.7788	3.008
MoH6	102	6.1%	0.459	0.308	0.074	1.146	0.1713	0.680
Total	1674	100.0%	0.694	1.895	0.042	55.2599	0.1476	0.611

Notes: *Royal Medical Services Hospitals; [†]Ministry of Health; [‡]University Hospital, [§]Private Hospitals; **Entrance Surface Dose; [¶]First Quartile; [#]Milli-Gray; ^{*}Third Quartile /Diagnostic Reference Level.

Discussion

Accurate establishment of NDRLs requires surveying diverse healthcare institutions to ensure data representation.²⁴ This study examined the ESD received by 1,674 paediatric patients, categorised into four non-overlapping age groups: 0 to <1 year, 1 to <5 years, 5 to <10 years, and 10 to ≤ 15 years.

International and national authorities advocate for compliance with the DRLs as a key tool for enhancing patient outcomes by minimising unnecessary radiation exposure while ensuring diagnostic consistency.⁹ Paediatric patients demonstrate increased radiosensitivity attributed to their developing tissues and extended life expectancy, which requires careful dose optimisation.²⁵ DRLs offer a framework for recognising and managing excessively high doses, ensuring that radiation exposure remains at levels essential for meeting clinical goals while maintaining safety standards.^{17,26} Minimising variability in imaging practices enhances diagnostic confidence and consistency across institutions. Furthermore, compliance with NDRLs guarantees that all healthcare sectors have equitable access to optimal radiation doses.²⁷

This study is the first nationwide endeavor in Jordan to establish NDRLs based on ESD values and assess DRLs for paediatric pelvic X-rays. The findings indicate an ESD third quartile (Q3/DRL) of 0.612 mGy and a mean ESD of 0.694 mGy. Comparing Jordanian DRLs with international benchmarks reveals both similarities and discrepancies, as shown in Table 4. The DRL established in this study is lower than those reported in Iraq (1.88 mGy)³⁴ and Nigeria (0.85 mGy),^{17,28} yet they are comparable to Saudi Arabia (0.63 mGy)²³ and Iran (0.59 mGy).³ In contrast, Jordanian DRLs exceed those recorded in Portugal (0.192–0.573 mGy)²⁶ and Kenya (0.1–0.36 mGy).²⁸ The large variety of ESD values (0.04–55.26 mGy) in this study is due to the bigger sample size of 1,674 compared to 240 to 450 in Ademola's study and the broad range of digital radiography.¹¹

The variations in DRLs among different studies and countries arise from disparities in healthcare infrastructure, imaging techniques, patient demographics, radiographic protocols, equipment calibration, and regulatory standards.³⁵ This study used digital radiography, which normally reduces radiation doses as compared to traditional techniques.³⁶ Research involving smaller sample sizes may yield elevated DRLs due to patient variability, while larger datasets, as

Table 4 Comparison of DRL[†] Values (mGy) [‡]in Jordan with Internationally Published DRLs

Study	Age-Groups				Country
	0 to <1Year	1 to <5Years	5 to <10Years	10 to ≤15Years	
This study	0.2653	0.3822	0.7038	0.9952	Jordan
Hart ²⁹	0.500	0.600	0.700	2	UK
Charles M, UNSCEAR ^{30¶}	0.07	0.08	0.04	1.13	Many countries
Hart D et al, 2010 ³¹	0.210	–	0.600	1.300	UK
Wambani et al, 2012 ¹⁵	0.100	0.120	0.250	0.360	South Kenya
Paulo et al, 2016 ¹⁶	0.098	0.132	0.192	0.573	Portugal
Zewdu et al, 2017 ¹⁷	**	11.05	15.79	25.03	Ethiopia
Deevband et al, 2018 ³²	0.47	0.91	1.23	1.51	Iran
Rana et al, 2018 ³³	0.189	0.171	0.299	0.498	India
Seife Teferi et al, 2020 ³⁴	**	0.88	1.6	**	Ethiopia
European Commission ²²	0.256	0.475	0.807	0.892	Ireland

Notes: [†]Diagnostic Reference Level; [‡]milli-Gray; **indicates this category of age group was not involved in the study; [¶]United Nations Scientific Committee on the Effects of Atomic Radiation.

used in this study, offer more accurate dose estimates.²⁸ Exposure parameters, including kVp, mA, and FSD, significantly affect radiation dose levels.³⁷ Countries with established NDRLs frequently report lower DRLs as a result of strict compliance with international radiation safety standards.^{38,39} Higher DRLs in Iraq and Ethiopia (15.79–25.03 mGy for older paediatric patients) indicate challenges including limited access to advanced radiographic equipment, inconsistent protocols, and insufficient training. To align Jordanian practices with global standards, investment in infrastructure, regulatory oversight, and improved radiology training programs is necessary.

As depicted in Figure 1, the ESD demonstrates an increase with age, suggesting that greater radiation doses are required for older patients due to anatomical differences.

Statistical analysis using ANOVA (P-value = 0.001; Table 1) revealed significant variations in average ESD across different age groups, a crucial insight for the accurate determination of age-based DRLs. This trend aligns with findings from the majority of DRL studies.^{15–17,26,31–34} Furthermore, the DRL values presented in this study are lower than those

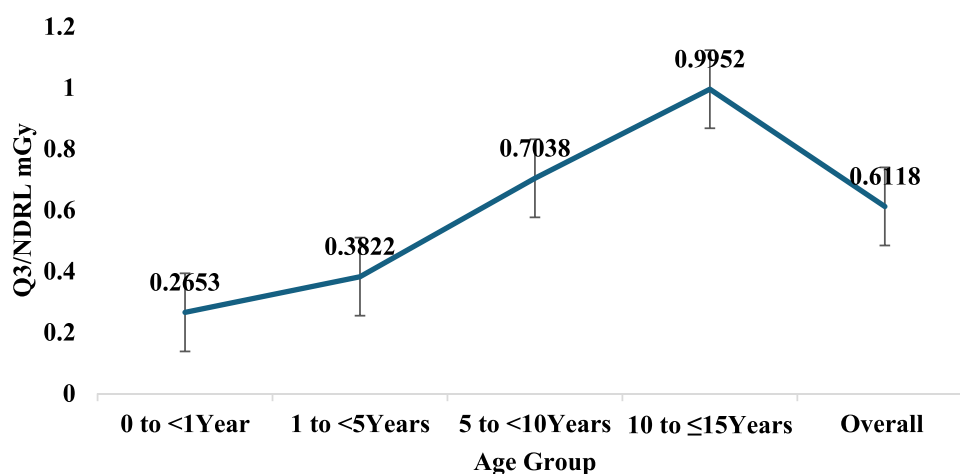


Figure 1 The (Q3/DRL) for (ESD) across paediatric age groups and the total population in Jordan.

documented by Zewdu et al,¹⁷ Deevband et al,³² the National Radiological Protection Board (NRPB)-W14 report,²⁹ and Seife Teferi et al,³⁴ yet they exceed those reported by Wambani et al,¹⁵ Paulo et al,¹⁶ and Rana et al.³³

In contrast, the DRL values in this study are mostly higher than those in the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) report, except for the age group of 10 to 15 years, where this study shows a lower value of 0.9952 mGy compared to 1.13 mGy in the UNSCEAR report.

This variation in DRL values across age groups is also apparent in similar studies conducted in European countries.⁹

A comparison of the ESD values across healthcare sectors reveals substantial differences in radiation exposure practices from the NDRL of 0.611 mGy, as illustrated in Figure 2.

The observed variations in DRLs among healthcare sectors underscore the necessity for standardised equipment and protocols.³³ Such differences frequently stem from variations in imaging parameters like kVp and filtration, patient habits, equipment calibration, operator proficiency, and institutional protocols. The inconsistent use of Automatic Exposure Control (AEC) and the absence of dedicated paediatric radiology units in numerous facilities further amplify these discrepancies.^{11,17,28}

Mitigating these issues necessitates regulatory supervision, specialised training, and investments in contemporary radiography technology to guarantee adherence to national and international standards.¹¹ Institutions such as MOH and RMSH had considerable ESD variability, with MOH surpassing the national DRL by 52%. Conversely, UNIV and PRIV exhibited superior dose optimisation. Improving training and performing regular audits are crucial for aligning practices with NDRLs and ensuring uniform radiation safety across the nation.^{11,17}

Considerable variability in radiation doses among hospitals was observed in this study, stemming from differences in exposure parameters including kVp, mAs, and FSD. A key finding was that kVp values for younger age groups frequently did not align with European Commission recommendations (60–80 kVp for 0–1 year; 100–120 kVp for 5 years and older).^{9,24,32} This discrepancy is likely due to the lack of a standardised NDRL, inconsistent quality control, and operator-dependent practices. Implementing kVp settings according to these guidelines could standardise dose levels and minimise unnecessary radiation exposure.⁴⁰ Although FSD values were consistently 100 cm, optimising other parameters such as filtration and AEC remains crucial for improving dose uniformity and reducing overall variability.^{9,31,41}

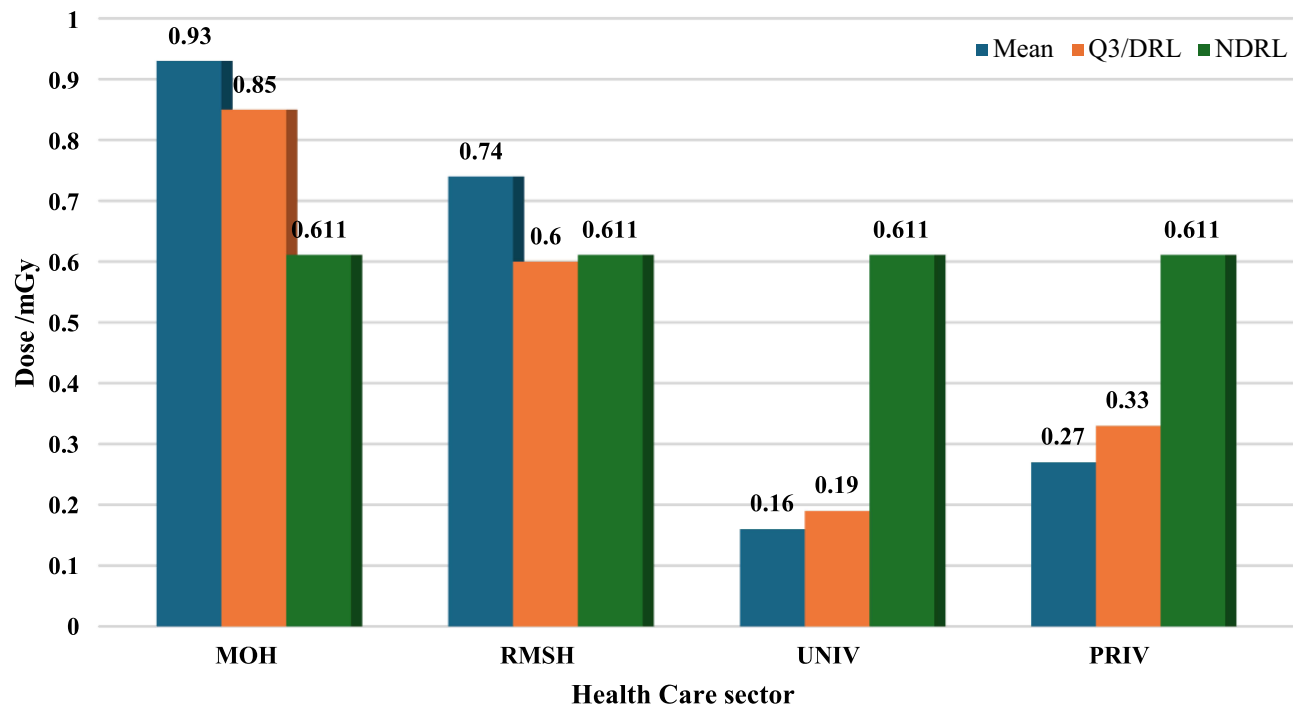


Figure 2 Comparison of the ESD, (Q3/DRL), and (NDRL) across healthcare sectors in Jordan.

The study's findings reveal significant challenges in paediatric radiology, such as insufficient training for imaging personnel and the lack of specialised paediatric radiology units.¹⁷ Many Jordanian facilities utilise general X-ray equipment, which may not be optimised for paediatric imaging, resulting in inconsistent radiation doses. These disparities underscore the need for dedicated paediatric imaging departments and continuous educational initiatives for radiology staff.¹¹ These initiatives are vital for achieving compliance with NDRLs and guaranteeing equitable access to safe, high-quality imaging for all paediatric patients, thereby meeting international radiation protection requirements.

Apart from infrastructure development and training monitoring, adherence to NDRLs is vital for their effective implementation.³⁹ These systems aggregate dose data from multiple healthcare institutions and generate reports for regulatory oversight, facilitating continuous evaluation and refinement of NDRLs. Additionally, automated dose monitoring software, when integrated with imaging equipment, offers real-time feedback to radiology teams, facilitating adherence to dose thresholds and highlighting areas for improvement.¹⁵ Routine audits and institutional dose reviews would enhance compliance with NDRLs, reduce variability in exposure levels, and improve overall patient safety within Jordanian healthcare sectors.³⁷ These regulatory measures, when implemented effectively, would enhance adherence to NDRLs, decrease variability, and strengthen patient safety across the nation.

This study establishes a benchmark for paediatric pelvic X-ray radiation doses in Jordan, though its generalisability beyond the sample should be acknowledged. The inclusion of multiple healthcare sectors—public, university, military, and private hospitals—enhances the findings' relevance to the broader Jordanian healthcare system. However, variations in imaging protocols, equipment calibration, and operator experience among institutions may limit direct extrapolation to other countries or regions with different healthcare infrastructures. Despite this, the study's adherence to international dose assessment methodologies makes it a valuable reference for establishing NDRLs in similar contexts, particularly in Middle Eastern or developing nations facing comparable radiographic practices and healthcare challenges. Future research incorporating additional regions and larger datasets could further validate these findings globally.

Limitations of the Study

This study, despite extensive data gathering and analysis, is subject to certain limitations. The retrospective nature of the research could have introduced biases during data collection. Moreover, the sample size may not fully represent the Jordanian paediatric population, which limits the generalisability of the findings. Additionally, variations in imaging equipment and techniques across healthcare facilities might have impacted the accuracy and reliability of the study's outcomes.

Conclusion

This study established an NDRL of 0.6118 mGy for paediatric pelvic X-rays in Jordan, illustrating that radiation dose is age-dependent and varies among healthcare facilities. This variation stems from factors including exposure settings, technician proficiency, and quality control protocols. The study's retrospective methodology and inherent data variability constitute its primary limitations. Future research should prioritise longitudinal DRL studies, concerted quality control initiatives, and the refinement of paediatric imaging techniques. These endeavours are essential for augmenting radiation safety and informing national guidelines to foster consistent and safer imaging practices.

Data Sharing Statement

The data that supports the findings of this study is available from the corresponding author upon reasonable request.

Ethical Approval

This retrospective study received approval from the IRB at Jordan University of Science and Technology (Approval No. 34/164/2023, dated 1/11/2023), confirming adherence to ethical standards. The study aimed to establish DRLs for radiation exposure from digital paediatric pelvic X-rays in Jordan, utilising anonymised, pre-existing healthcare data without direct patient involvement. Parental consent was waived by the IRB due to the absence of patient interaction and identifiable information. Data management followed stringent confidentiality protocols, ensuring patient privacy and upholding the ethical principles of the Declaration of Helsinki.

Author Contributions

The authors collectively made significant contributions to this work, from its initial conception and study design through execution, data acquisition, analysis, and interpretation. They were all involved in drafting, revising, or critically reviewing the article, granted final approval for the version to be published, agreed on the journal for submission, and assume joint accountability for all aspects of the work.

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Disclosure

The authors declare that they have no conflicts of interest in this work.

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