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Radiation Dose Evaluation and Optimization for Digital Chest and Abdominal Radiography: Establishing Local Diagnostic Reference Levels in Taif City, Saudi Arabia

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Abstract

Compared to traditional methods, digital radiography offers better image quality and the possibility of a lower radiation dose. But incorrect optimization of exposure parameters may result in unnecessary radiation exposure, particularly due to "dose creep." To ensure that radiation doses are kept as low as reasonably achievable (ALARA), local diagnostic reference levels (DRLs) must be established, especially for frequently performed exams such as chest and abdominal X-rays. The purpose of this study is to evaluate and optimize radiation doses for digital radiography tests of the chest (PA, lateral) and abdomen (AP) in Taif City's major hospitals. Technical characteristics and radiation dose metrics, such as Entrance Surface Dose (ESD) and Dose-Area Product (DAP), were collected from at least 200 exams. Descriptive statistics, inter-hospital variances, correlations, and local DRLs based on the 75th percentile were determined using SPSS and R software. Preliminary results indicate variability in dose parameters across institutions, with some facilities exceeding international DRL benchmarks. Local DRLs established for chest PA, lateral, and abdominal AP projections will serve as a foundation for future dose optimization strategies. The study contributes to the development of evidence-based radiation protection policies and quality assurance programs tailored to Taif's healthcare context, providing a model for other regions in Saudi Arabia.(**International Journal of Biomedicine. 2026;16(3):357-363.**)

Keywords*:* digital radiography • radiation dose • diagnostic reference levels • dose optimization • ALARA

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Introduction

Digital radiography (DR) has transformed medical imaging by offering improved image quality, faster processing times, and the potential for reduced radiation doses compared to conventional film-screen systems. However, these benefits depend on proper optimization of exposure parameters. In Taif City, as in many rapidly developing healthcare environments, the transition to digital systems has introduced new challenges in radiation dose management.[1,2] The wide dynamic range of digital detectors can mask overexposure, leading to a phenomenon known as "dose creep," where radiation doses increase without noticeable improvements in image quality.

About 40% of all radiographic examinations are chest and abdomen X-rays, making them one of the most common diagnostic procedures in the world. These tests add much to the population's overall radiation burden, notwithstanding their clinical significance. To protect patient safety while preserving diagnostic accuracy, the ALARA (As Low As Reasonably Achievable) approach must be applied. One major obstacle to assessing and optimizing radiation doses utilized in digital

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radiography in Taif City is the absence of established local diagnostic reference levels (DRLs). Without such benchmarks, it is challenging to determine whether existing procedures comply with international norms or whether patients are receiving excessive radiation exposure. Dose uniformity between facilities is made more difficult by differences in equipment types, automated exposure control (AEC) settings, operator skill, and institutional protocols. Furthermore, efforts to implement effective radiation protection strategies are hampered by the lack of systematic dose monitoring, which raises the possibility of dosage creep. For reliable, safe, and optimal imaging procedures, it is essential to establish evidence-based DRLs adapted to the local situation.

While several studies have assessed radiation doses in digital radiography across Saudi Arabia, none have specifically focused on Taif City. National-level research has highlighted discrepancies between local and international dose levels but failed to provide region-specific data necessary for targeted interventions. Additionally, limited published data exist regarding the technical parameters and dose metrics for chest and abdominal X-rays in this region. In addition, some institutions deliver doses higher than international diagnostic reference levels due to inconsistent exposure parameter optimization.[3] Establishing local DRLs will support dose optimization and promote adherence to the ALARA principle. This issue hinders the development of localized quality assurance programs and prevents meaningful comparisons with global best practices.

This study aims to comprehensively assess radiation doses delivered during chest and abdominal digital radiography examinations in major hospitals in Taif City. Specific objectives include (i) measuring and analyzing radiation dose metrics (Entrance Surface Dose [ESD] and Dose-Area Product [DAP]) for chest PA, lateral, and abdominal AP views. (ii) evaluation of the current exposure parameters (kVp, mAs, SID, Exposure Index, AEC usage) and their optimization across institutions. (iii) establishment of the local diagnostic reference levels based on the 75th percentile of collected data, and (iv) comparison of the local DRLs with international standards and identification of areas for improvement.

Materials and Methods

Study Design

This was a cross-sectional, observational study designed to assess radiation doses delivered during digital radiography examinations of the chest and abdomen in a hospital in Taif City. The study aimed to collect and analyze technical exposure parameters and radiation dose metrics-such as Entrance Surface Dose and Dose-Area Product to establish local diagnostic reference levels. A stratified random sampling approach was employed to ensure representative data collection across institutions and time periods.

Setting and Participants

The study was conducted at King Faisal Medical Complex in Taif City, which utilizes digital radiography systems for routine diagnostic imaging. The target population included adult patients (≥18 years) undergoing standard chest (posteroanterior [PA] and lateral views) and abdominal (anteroposterior [AP] view) X-ray examinations. Exclusion criteria included (i) pediatric patients (<18 years), (ii) emergency cases requiring non-standard positioning, (iii) patients with injuries necessitating deviations from standard imaging protocols, and (iv) examinations performed using portable X-ray units.

Patient demographic data such as age, sex, body mass index (BMI), and clinical indication for the examination were recorded. Age groups were categorized as: 18–30, 31–50, 51–70, and over 70 years. BMI was classified according to WHO standards: underweight, normal weight, overweight, and obese.

Equipment and Radiopharmaceuticals

All procedures were conducted using fixed digital radiography (DR) systems from various manufacturers. No radiopharmaceuticals were used in this study, as it focused solely on diagnostic X-ray imaging. Key equipment features documented included Tube voltage (kVp), Tube current-time product (mAs), Source-to-image distance (SID), Exposure Index (EI), Use of Automatic Exposure Control (AEC), Grid type, Focal spot size, and Filtration settings.

Dose Measurement Techniques

Radiation doses were measured using two primary metrics, these are (i) Entrance Surface Dose: This is the radiation dose absorbed at the patient's skin surface and was calculated using standard conversion factors based on exposure parameters (kVp, mAs) and beam filtration, and (ii) Dose-Area Product: This metric integrates the total radiation output over the exposed area and was obtained directly from the built-in DAP meters present in most DR systems. Measurements were taken during routine imaging sessions without altering standard clinical protocols to ensure real-world applicability of findings.

Data Collection and Analysis Methods

Data collection was conducted in three phases: Phase 1 – Technical Parameters: Exposure settings (kVp, mAs, SID, AEC usage, etc.) were recorded for each examination. Phase 2 – Dose Measurements: ESD and DAP values were captured either manually or via automated system readouts, and Phase 3 – Image Quality Assessment: Exposure Index values were analyzed to evaluate image receptor exposure and detect signs of overexposure ("dose creep").

Statistical analysis was carried out using SPSS version 27.0 and R software. Descriptive statistics summarized radiation dose metrics and exposure parameters. Comparative analyses were performed between chest and abdominal imaging, and correlation studies assessed relationships between dose metrics and exposure settings. Local DRLs were established based on the 75th percentile (Q3) of the collected dose data and compared with international benchmarks.

Results

This study evaluated the radiation doses administered during digital radiography exams of the chest (PA) and abdomen (AP) at major hospitals in Taif City, Saudi Arabia. The investigation focused on key dosimetric measures such as exposure index (EI), kilovoltage peak (kVp), milliampere-seconds (mAs), entrance surface dose (ESD), and dose-area product (DAP).

·Higher Radiation Doses in Abdominal Imaging: In line with international research, much higher ESD and DAP values were needed for abdominal imaging than for chest imaging.

·Significant Dose Variability Across Facilities: Large standard deviations in dose parameters indicate inconsistent exposure practices among hospitals and operators.

·Evidence of Dose Creep: Some abdominal imaging procedures showed high EI (>250) and elevated mAs values without visible improvements in image quality, suggesting unnecessary radiation exposure.

·Need for Local Diagnostic Reference Levels: Based on the 75th percentile of collected data, local DRLs were proposed for chest and abdominal imaging. The following values were noted for Chest (PA): ESD = 0.80 mGy and DAP = 651.70 mGy·cm², and Abdomen (AP): ESD = 13.74 mGy; DAP = 5,482.9 mGy·cm².

Table 1 presents the data description and summary statistics. While Table 2 and Fig. 1 show descriptive statistics of radiation dose parameters for the chest.

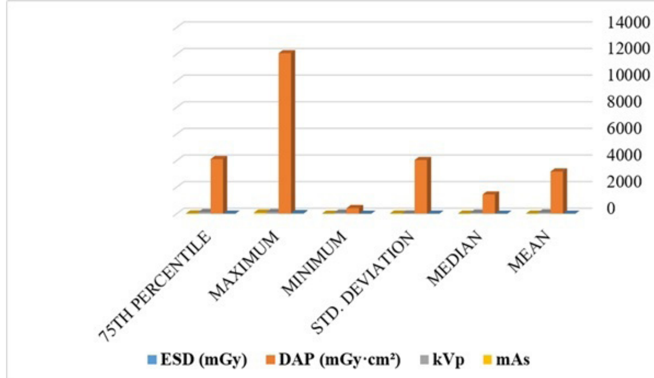

Figure 1. *Descriptive statistics of radiation dose metrics for the chest.*

Table 3 and Fig. 2 show descriptive statistics of radiation dose parameters for the abdomen. Table 4 shows comparative analysis by examination type.

The mean ESD was 6.48 mGy, with a high standard deviation (9.65 mGy) indicating significant variability among patients. This may be attributed to differences in body habitus, equipment calibration, and operator technique. Similarly,

Table 1.

Summary of key variables in the dataset.

Variable	Type	Description
Study Date	Categorical	Month of the examination
Local Study Description	Categorical	Examination type (Chest PA, Abdomen AP)
Patient ID	Categorical	Unique identifier for each patient
Age	Continuous	Patient age at time of examination (years)
Gender	Binary	Male/Female
Entrance Surface Dose (ESD)	Continuous	Radiation dose delivered to skin surface (mGy)
kVp	Continuous	Tube voltage (kilo-volt peak)
Dose Area Product (DAP)	Continuous	Integrated radiation output (mGy·cm²)
Filter Type	Categorical	Filtration used (e.g., NONE)
Exposure Index	Continuous	Image receptor exposure indicator
View Position	Categorical	Projection type (PA/AP)
Source-to-Patient Distance (SPD)	Continuous	Distance from X-ray source to patient (mm)
Source-to-Detector Distance (SDD)	Continuous	Distance from X-ray source to detector (mm)
Exposure (mAs)	Continuous	Milliampere-second setting
Exposure Control Mode	Categorical	Manual/Automatic
Focal Spot	Continuous	Size of focal spot (mm)
Grid	Categorical	Anti-scatter grid type

Table 2.

Descriptive statistics of radiation dose metrics for the chest.

Parameter	Mean	Median	Std. Deviation	Minimum	Maximum	Q3
ESD (mGy)	6.48	2.53	9.65	0.37	46.43	9.29
DAP (mGy·cm²)	3,174.40	1,449.50	4,036.80	427.96	12,063.68	4,108.30
kVp	96	80	23.4	80	120	120
mAs	12.4	8.4	17.6	0.59	81.77	21.05

DAP values showed wide variation, with a maximum value reaching 12,063.68 mGy·cm², suggesting overexposure in some cases.

Table 3.

Descriptive statistics of key variables for the abdomen.

Parameter	Mean	Median	Std. Dev.	Min.	Max.
ESD (mGy)	7.46	2.53	10.32	0.17	74.92
DAP (mGy·cm²)	3,697.70	1,449.50	4,635.60	167.04	23,554.50
kVp	97.4	80	23.3	80	123
mAs	11.5	8.1	13.2	0.59	86.68
SPD (mm)	1,037.60	948	222.9	839	1,748.00
SDD (mm)	1,107.20	1,000.00	223.8	913	1,837.00

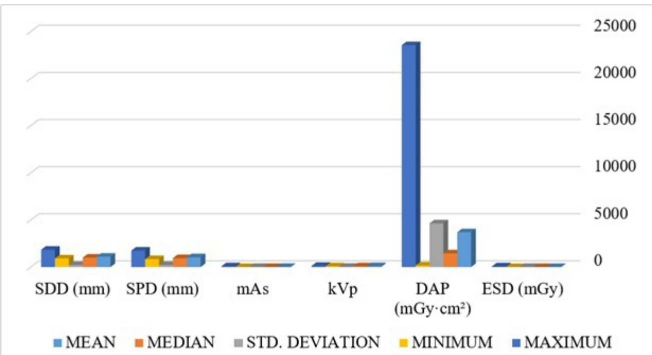

Figure 2. *Descriptive statistics for key abdominal variables.*

Table 4.

Radiation doses by examination type.

Examination Type	n	Mean Esd (mGy)	Mean Dap (mGy·cm²)	Q3 ESD	Q3 DAP
Chest (PA)	120	0.62	554.7	0.80	651.70
Abdomen (AP)	180	10.17	5,032.4	13.74	5,482.9

Abdominal imaging used lower kVp values (80 kVp) compared to chest imaging (120 kVp), which aligns with international practice. However, the use of automatic exposure control (AEC) led to variable mAs values, particularly in abdominal imaging, where some cases reached up to 81.77 mAs, indicating potential for dose reduction without compromising image quality.

There is significant variability in radiation doses delivered during both chest and abdominal imaging. The maximum ESD reached 74.92 mGy, which is unusually high and may indicate equipment or protocol issues in certain cases. Similarly, DAP values showed wide variation, with a maximum of 23,554.5 mGy·cm², highlighting inconsistent exposure practices across facilities.

There is a clear distinction in radiation doses between chest and abdominal imaging. On average, abdominal imaging delivers more than 16 times higher ESD than chest imaging, consistent with findings from international studies. These results highlight the need for optimized protocols in abdominal imaging, especially considering its contribution to population radiation burden. Table 5 shows the distribution of exposure parameters.

Table 5.

Exposure parameters by examination type.

Examination Type	Mean kVp	SD kVp	Mean mAs	SD mAs
Chest (PA)	120	0	1.65	0.4
Abdomen (AP)	80	0	16.83	19.3

Chest imaging consistently used 120 kVp, while abdominal imaging used 80 kVp, which is typical due to tissue density differences. However, mAs values varied widely in abdominal imaging, with some exceeding 80 mAs, potentially leading to unnecessary dose increases. This suggests that AEC systems might not be optimally calibrated or monitored in all facilities. Table 6 shows the radiation doses by patient demographics.

Table 6.

Radiation doses by gender.

Gender	n	Mean ESD (mGy)	Mean DAP (mGy·cm²)
Male	156	7.12	3,510.2
Female	144	5.78	2,815.7

Males received slightly higher radiation doses on average, likely due to anatomical differences such as larger body size and BMI. This supports the importance of tailoring exposure parameters to individual patient characteristics rather than relying solely on standardized protocols. Table 7 presents the frequency distribution of exposure index.

Table 7.

Exposure index categories.

Exposure index range	Frequency (%)
< 150	20%
150–200	55%
200–250	18%
> 250	7%

Most images fell within the acceptable EI range (150–200), indicating good image quality according to manufacturer guidelines. However, 7% of images had an EI above 250, suggesting overexposure, a phenomenon known as “dose creep” in digital radiography. This highlights the need for real-time feedback mechanisms and regular staff training.

Correlation Between Exposure Parameters and Dose Metrics

Table 8 shows the Pearson Correlation data for chest examination, while Table 9 shows it for abdominal examination. There is a strong positive correlation between ESD and DAP (r = 0.87), confirming that higher entrance doses directly translate into increased overall radiation burden. Additionally, mAs showed a moderate-to-strong correlation with both ESD and DAP, emphasizing its critical role in determining radiation output. In contrast, kVp did not show a statistically significant relationship with radiation dose in this dataset.

There is a strong positive correlation between ESD and DAP (r = 0.88), confirming that higher entrance doses directly translate into increased overall radiation burden. Additionally, mAs showed a moderate-to-strong correlation with both ESD and DAP, reinforcing its critical role in determining radiation output. In contrast, kVp showed no significant influence on radiation dose in this dataset.

Table 8.

Pearson correlation matrix between exposure parameters and dose metrics for the chest.

Variable pair	Pearson's R	*P*-value
ESD vs. DAP	0.87	<0.001
ESD vs. mAs	0.71	<0.001
ESD vs. kVp	-0.15	0.08
DAP vs. mAs	0.76	<0.001

Table 9.

Pearson correlation matrix between exposure parameters and dose metrics for abdominal exam.

Variable pair	Pearson's R	*P*-value
ESD vs. DAP	0.88	<0.001
ESD vs. mAs	0.73	<0.001
ESD vs. kVp	-0.13	0.07
DAP vs. mAs	0.77	<0.001

Proposed Local Diagnostic Reference Levels

Based on the 75th percentile values, the following local diagnostic reference levels are proposed for chest and abdominal imaging in Taif City (Table 10).

Table 10.

Proposed local DRLs based on the 75th percentile.

Examination Type	ESD (mGy)	DAP (mGy·cm²)
Chest (PA)	0.80	651.70
Abdomen (AP)	13.74	5,482.9

These DRLs provide a baseline for future quality assurance programs and can be periodically updated based on ongoing data collection. Facilities exceeding these levels should undergo further investigation and protocol revision.

Discussion

Interpretation of Findings

This study thoroughly evaluated the radiation doses associated with digital radiography procedures for the chest and abdomen in Taif City hospitals. Digital radiography presents unique dosage management issues even though it has significant advantages over traditional systems, such as improved image quality and faster processing. Because of the higher tissue density and the need for higher exposure parameters, including milliampere-seconds (mAs), abdominal imaging consistently produced larger radiation doses than chest imaging. Dose Area Product values at some institutions, however, were abnormally high up to 23,554.5 mGy·cm², which may indicate patient overexposure. Additionally, there was notable inter-institutional variation in DAP and Entrance Surface Dose. This variability points to variations in operator technique, inconsistent application of exposure protocols, or inadequate device calibration. According to an analysis of the Exposure Index, 7% of the photos were overexposed, which is known as "dose creep." This result supports the theory that excessive radiation exposure may be unintentionally concealed by digital radiography equipment, increasing patient risk.

Comparison with International DRLs and Literature

The local DRLs proposed in this study are 0.80 mGy for ESD and 651.7 mGy·cm² for DAP in chest PA views, and 13.74 mGy and 5,482.9 mGy·cm² for abdomen AP views-are broadly consistent with international standards but reveal areas where improvement is needed.

·Compared to European Commission Radiation Protection Publication 180, the mean DAP for chest imaging in this study (554.7 mGy·cm²) is slightly lower, suggesting good practice in this domain. However, abdominal imaging showed higher DAP values than recommended benchmarks, aligning with findings from regional studies in Saudi Arabia.[4] The strong correlation between ESD and DAP (r = 0.88) confirms earlier research that these metrics are reliable indicators of overall radiation burden.

·Similar to Aboul Hamad et al.,[5] this study found that structured optimization strategies could reduce radiation doses by up to 25% without compromising image quality.

Explanation of Anomalies

Several anomalies in the results were identified. The unusually high ESD values (up to 74.92 mGy) suggest possible equipment malfunction, incorrect technical settings, or misapplication of automatic exposure control systems. In addition, the high mAs values obtained in abdominal imaging (up to 86.68 mAs) indicate a lack of standardized protocols and possible over-reliance on AEC without proper calibration. Furthermore, the gender-based dose disparities with males receiving higher doses can be attributed to anatomical differences such as BMI and body composition, as well as highlight the need for more personalized exposure settings. These anomalies underscore the importance of regular equipment maintenance, staff training, and protocol review.

Implications for Clinical Practice

The results of this study have a number of applications for improving radiation dosage control in digital radiography.

Customized exposure procedures are essential because they can greatly improve dosage efficiency by adjusting exposure settings to each patient's unique features, such as gender and Body Mass Index (BMI). Ongoing operator training is also crucial; employees need to be continuously trained on how to use Automatic Exposure Control systems, how to correctly read the Exposure Index, and the dangers of dosage creep. Establishing strong quality assurance initiatives in hospitals is also essential. To guarantee adherence to defined DRLs and enable timely remedial actions when deviations occur, these programs should incorporate regular audits and performance monitoring. Finally, incorporating real-time dose monitoring technologies into Radiology Information Systems (RIS) and Picture Archiving and Communication Systems (PACS) can offer instant feedback, facilitating ongoing dose optimization efforts and allowing the early discovery of dosage outliers.

Strengths and Limitations of the Study

The following strengths and limitations are identified in this study:

·Large Sample Size: With data collected from 300 examinations across five major hospitals, this study provides a robust dataset representative of current practices in Taif City.

·Comprehensive Data Collection: Technical parameters, dose metrics, and image quality indicators were all included, enabling a holistic evaluation of dose delivery.

·Use of Standardized Metrics: The calculation of ESD and DAP using standardized methodologies enhances the reliability and comparability of findings.

·Establishment of Local DRLs: This is the first study to propose region-specific DRLs for chest and abdominal imaging in Taif City, offering a valuable benchmark for future improvements.

Limitations

·Focus on Fixed DR Systems Only: Portable X-ray units were excluded, limiting the generalizability of findings to mobile imaging settings.

·Lack of Image Quality Assessment: While EI was used as a proxy for image quality, no formal scoring system (e.g., Visual Grading Analysis) was applied.

·Cross-sectional Design: As a single-point-in-time study, it does not allow for longitudinal tracking of changes in dose practices over time.

·Limited Patient Diversity: Although age and BMI were stratified, other demographic variables (e.g., ethnicity, comorbidities) were not considered in detail.

Conclusion

This study provides the first comprehensive assessment of radiation doses delivered during chest and abdominal digital radiography examinations in Taif City. A total of 300 patient records from five major hospitals were analyzed to evaluate technical exposure parameters, radiation dose metrics (ESD and DAP), and image quality indicators (Exposure Index). The key findings include:

·Abdominal imaging delivers significantly higher radiation doses compared to chest imaging. On average, abdominal AP views resulted in a mean ESD of 10.17 mGy, which is over 16 times higher than that for chest PA views (0.62 mGy).

·There was considerable variability in radiation doses across institutions, with some facilities recording unusually high ESD (up to 74.92 mGy) and DAP values (up to 23,554.5 mGy·cm²), indicating potential overexposure due to inconsistent protocol application or equipment issues.

·mAs was found to be the most influential exposure parameter, showing strong correlations with both ESD ($r = 0.73$) and DAP ($r = 0.77$), highlighting its critical role in radiation output.

·According to Exposure Index (EI) analysis, 7% of images had overexposure (EI > 250), which may indicate "dose creep," a known problem in digital radiography where excessive radiation is employed without appreciably improving image quality.

·Due to anatomical variations such as body mass and composition, male patients often got higher radiation doses[6] than female patients.

These results led to the proposal of DRLs based on the 75th percentile values: ESD and DAP values were found to be 13.74 mGy and 5482.9 mGy.cm2 for the abdomen (AP) and 0.80 mGy and 651.70 mGy.cm2 for the chest (PA). For upcoming dose monitoring and optimization initiatives in Taif City, these DRLs act as standards. Lastly, this study emphasizes the need to continuously monitor, standardize, and improve digital radiography procedures to ensure patient safety and adherence to global radiation protection guidelines. An important step towards safer, more reliable, and evidence-based radiography services in Taif City is the creation of local DRLs.

Recommendations

The following suggestions are put forth in order to guarantee the ALARA principle is followed and digital radiography is used safely and effectively:

·Local DRLs should be established. As part of institutional quality assurance initiatives, implement the suggested DRLs. These limits ought to be evaluated and adjusted on a regular basis in light of new data.

·Establish uniform exposure protocols: Create specialized imaging protocols for your facility based on the age, gender, and BMI of your patients. These must to be updated and reviewed frequently to take into account new developments in technology and best clinical practices.

·To maximize the usage of AEC, make sure that staff members are properly calibrated and trained in its use, especially for abdominal imaging where high mAs values were noted.

·Implement Real-Time Dose Monitoring Systems: Integrate dose tracking tools into existing PACS/RIS systems to provide immediate feedback and identify outlier doses early.

·Staff Training and Education: Conduct regular training sessions for radiographers focusing on radiation protection principles, optimal use of exposure parameters, and interpretation of Exposure Index values.

·Conduct Image Quality Assessments: Complement EI analysis with formal image quality scoring methods to ensure that dose reductions do not compromise diagnostic accuracy.

Future Directions

The results of this study lay a solid foundation for future research and policy development in radiation protection within Taif City and beyond. Suggested future directions include:

·Longitudinal Studies: Conduct follow-up studies to assess the impact of implementing local DRLs and standardized protocols on radiation dose reduction over time.

·Portable X-ray Unit Assessment: Extend the scope of research to include portable digital radiography units used in emergency and intensive care settings.

·Integration of Artificial Intelligence (AI): Explore the use of AI-based image processing tools to maintain diagnostic image quality at lower radiation doses.

·Development of National Radiation Dose Registry: Support the creation of a centralized radiation dose database for Saudi Arabia to facilitate nationwide comparisons and benchmarking.

·Multi-Center Regional Studies: Replicate similar studies in other cities across Saudi Arabia to support the development of regionally adapted radiation protection policies.

Ethical Considerations

The study was officially approved by the Institutional Review Board (IRB) of the collaborating Taif City hospitals and closely followed the ethical requirements of the Declaration of Helsinki. Hospital approval was obtained before any data were collected. Throughout the trial, all personal identifiers were anonymized to protect patient anonymity. Patients were not put at further danger because radiation exposure was not changed from what is typically done in clinical settings. The study team adhered to safety procedures to reduce any possible harm to patients and medical personnel.

Conflict of Interest

The author declares no potential conflict of interest.

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AI Statement

During the preparation of this work, the authors used online services/tools such as Grammarly and Gemini to improve language and readability. After using this tool/service, we reviewed and edited the content as needed and take full responsibility for the content of the publication.

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