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Analysis of Radiation Dose Optimization in X-Ray Imaging: Focusing on Patient Safety while Maintaining High-Quality Diagnostic Imaging Standards

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Abstract: Background: Diagnostic X-ray imaging provides essential clinical information but involves ionizing radiation, making optimization necessary to protect patients while preserving diagnostic image quality. The ALARA principle requires exposures to be kept as low as reasonably achievable without compromising the clinical purpose of the examination. Objective: To assess knowledge, attitudes, and routine practices related to radiation dose optimization among imaging professionals and to examine associations with professional role, years of experience, and healthcare facility type. Methods: A descriptive analytical cross-sectional questionnaire study was conducted among 384 imaging professionals involved in diagnostic X-ray imaging in Pakistan. Data were collected through a structured online questionnaire covering demographic characteristics, ALARA-related knowledge and attitudes, dose-optimization practices, and routinely used kVp and mAs values for common projections. Descriptive statistics and Pearson chi-square tests were performed. Results: The overall dose-optimization score was 3.64 ± 0.67 on a five-point scale. The strongest practice item was avoiding repeat exposures through careful positioning (3.82 ± 0.94), whereas awareness of international guidelines was lowest (3.52 ± 1.11). Mean routine parameters were 110.06 kVp/3.85 mAs for chest PA, 100.42 kVp/40.41 mAs for abdomen AP, 106.15 kVp/40.33 mAs for pelvis AP, and 97.95 kVp/29.65 mAs for skull AP. Dose-optimization grouping was significantly associated with professional role (χ^2=210.303, df=2, p<0.001), years of experience (χ^2=289.712, df=3, p<0.001), and facility type (χ^2=16.732, df=2, p<0.001). Conclusion: Imaging professionals demonstrated moderate dose-optimization practice, but important gaps remain in knowledge of international guidance and recommended dose ranges. Experience, professional role, and facility environment were significantly associated with optimization practice. Structured continuing education, standardized protocols, competency assessment, and dose-monitoring systems are recommended.

Keywords: Radiation dose optimization; X-ray imaging; patient safety; ALARA; diagnostic image quality; radiography; radiation protection.

INTRODUCTION

Medical imaging is fundamental to modern diagnosis and clinical decision-making. Conventional X-ray radiography remains one of the most frequently used imaging techniques because it is accessible, rapid, relatively inexpensive, and effective for many examinations. Since the discovery of X-rays by Wilhelm Conrad Röntgen in 1895, radiography has developed from film-based systems to digital radiography and increasingly automated acquisition technologies. These advances have improved image quality and workflow, but the use of ionizing radiation continues to require careful justification and optimization [Laal, M. 2013; Rehani, M. M., & Nacouzi, D. 2020; Seibert, J. A. 2004; Huda, W., & Abrahams, R. B. 2015; McCollough, C. H. 1997].

Radiographic image quality depends on exposure factors, patient characteristics, detector performance, positioning, collimation, scatter control, and operator expertise. Tube potential (kVp) affects beam energy and penetration, while tube current and exposure time determine mAs and strongly influence photon quantity. Appropriate selection of these factors is necessary to obtain an image that is diagnostically adequate without unnecessary exposure [Tafti, D., & Maani, C. V. 2023; Chen, H. *et al*., 2012; Uffmann, M., & Schaefer-Prokop, C. 2009; Stieve, F. E. *et al*., 1993; Rochmayanti, D. *et al*., 2019].

Radiation protection in medical imaging is based on justification, optimization, and dose limitation. For patients, optimization is commonly expressed through the ALARA principle: the dose should be kept as low as reasonably achievable while obtaining the clinical information required for diagnosis. The objective is therefore not a visually perfect image at any cost, but an image of sufficient quality for the clinical task [Faggioni, L. *et al*., 2017; Bárdyová, Z. *et al*., 2021; Franco, A. *et al*., 2016; Van der Merwe, B. 2014; Awosan, K. J. *et al*., 2016].

Overexposure can increase patient radiation burden, while underexposure can increase image noise and the likelihood of repeat examinations. Both situations can be undesirable. Modern digital systems may also mask overexposure because post-processing can produce an apparently acceptable image despite excessive detector exposure. Consequently, knowledge of exposure factors, diagnostic reference levels (DRLs), quality assurance, and dose-management principles is increasingly important [Javed, H. *et al*., 2019;

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Thakur, Y. *et al*., 2013; Tsapaki, V. *et al*., 2020; Khamtuikrua, C., & Suksompong, S. 2020; Babikir, E. *et al*., 2020].

Previous studies have identified gaps in radiation-safety knowledge among healthcare professionals and variation in dose and image-quality practices between institutions. Research has also demonstrated that systematic protocol review, staff education, equipment quality control, and dose monitoring can improve optimization [Zekioğlu, A., & Parlar, Ş. 2021; Aldahery, S. T. 2023; Alyousef, K. *et al*., 2023; Wenman, A., & Lockwood, P. 2024; Kleefeld, C. *et al*., 2024; Barau, N. I. *et al*., 2025; Whitebird, P. R. R. *et al*., 2022]. In Pakistan, evidence on how professional experience and facility type relate to day-to-day dose-optimization practice remains limited. The present study was therefore designed to assess these issues among imaging professionals working with diagnostic X-ray examinations.

Study Objectives

To assess knowledge, attitudes, and routine practices related to radiation dose optimization among imaging professionals involved in diagnostic X-ray imaging, examine the association between dose-optimization practice and professional role, years of clinical experience, and healthcare facility type and compare routinely reported kVp and mAs values for common X-ray examinations with the recommended ranges used in the study.

MATERIALS AND METHODS

Study Design and Participants

A descriptive analytical cross-sectional design was used. Participants were imaging professionals directly involved in routine diagnostic X-ray imaging. Recruitment used non-probability convenience sampling supplemented by a snowball approach, in which initial respondents were encouraged to share the online questionnaire with eligible colleagues. The calculated sample size was 384 participants [Samara, E. T. *et al*., 2022].

Study Setting and Data Collection

The study covered diagnostic radiology settings in Pakistan, including government hospitals, private hospitals, teaching hospitals, and private diagnostic imaging centres. Data were collected through an online Google Form. The questionnaire was distributed through professional radiography networks, email lists, and WhatsApp groups. The instrument was reviewed by subject experts before formal data collection, and minor wording changes were made to improve clarity.

Eligibility Criteria

Eligible participants were radiologists, radiologic technologists, senior radiographers, radiology trainees, and current or former medical imaging technology students who were directly involved in routine diagnostic X-ray imaging. Participants were required to be at least 18 years old and to provide voluntary consent. Non-radiology personnel, staff working exclusively with non-X-ray modalities such as ultrasound or MRI, individuals younger than 18 years, non-consenting individuals, and incomplete questionnaires were excluded.

Variables and Questionnaire

The independent variables included professional role, years of clinical experience, self-reported knowledge of ALARA and dose optimization, and routine exposure-factor choices. The primary outcome was radiation dose-optimization practice, operationalized through composite Likert-scale items addressing ALARA compliance, repeat-exposure avoidance, patient-size adjustment, collimation, filtration, exposure-factor selection, image-quality considerations, and overall dose responsibility.

The questionnaire contained demographic items, 20 five-point Likert-scale items concerning dose-optimization knowledge and practice, questions on routinely used kVp and mAs for chest PA, abdomen AP, pelvis AP, and skull AP examinations, and two overall perception items addressing patient safety and continuing training. Responses ranged from strongly disagree (1) to strongly agree (5).

Statistical Analysis

Data were exported from Google Sheets and analyzed using SPSS. Frequencies, percentages, means, and standard deviations were calculated. Composite scores were derived from relevant Likert items, with higher scores representing better optimization practice. Pearson chi-square tests were used to examine associations between dose-optimization group and professional role, years of experience, and facility type. Statistical significance was set at $p<0.05$.

Ethical Considerations

The study protocol was reviewed and approved by the Institutional Review Board of Riphah International University, Faisalabad Campus. Participation was voluntary. Completion and

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submission of the online questionnaire constituted informed consent. No names or direct identifiers were collected, and the dataset was stored in password-protected files for academic and research purposes.

RESULTS

A total of 384 valid responses were included. The overall dose-optimization score was 3.64 ± 0.67, indicating moderate-to-good self-reported practice on the five-point scale. Individual item means ranged from 3.52 to 3.82. The strongest items concerned avoiding repeat exposures through careful positioning (3.82 ± 0.94), appropriate shielding where applicable (3.81 ± 0.94), and maintaining the dose as low as reasonably achievable (3.78 ± 0.85). The weakest areas were awareness of international guidelines such as ICRP recommendations (3.52 ± 1.11), knowledge of recommended dose ranges (3.54 ± 1.07), and selection of parameters without affecting diagnostic quality (3.54 ± 1.01). Participants also strongly endorsed the importance of dose optimization for patient safety (3.74 ± 0.92) and continuing training (3.80 ± 0.93).

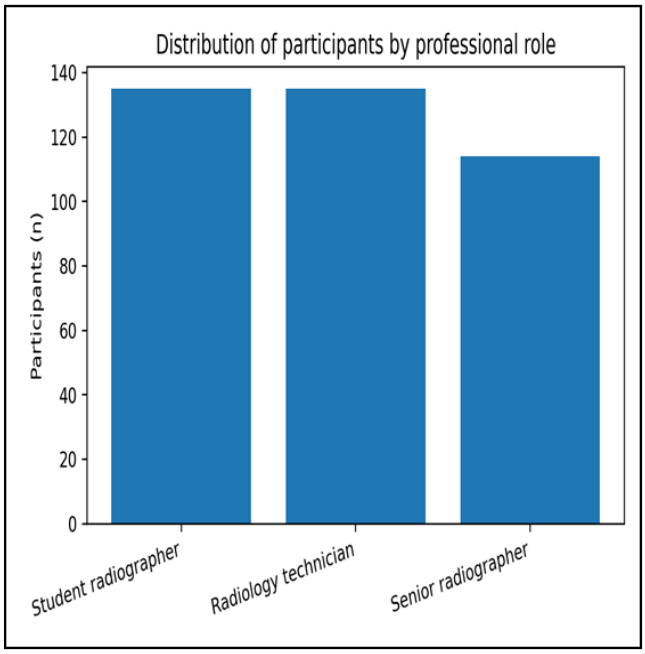


Figure 1. Distribution of participants by professional role.

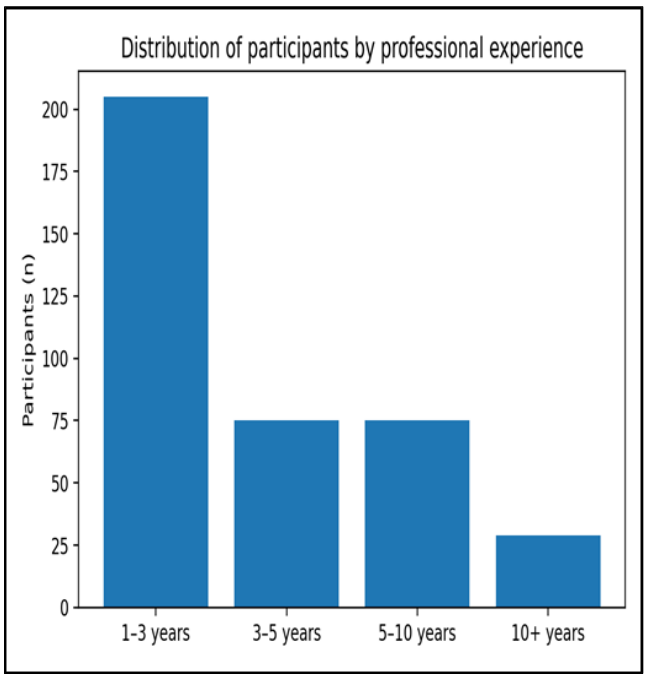


Figure 2. Distribution of participants by professional experience.

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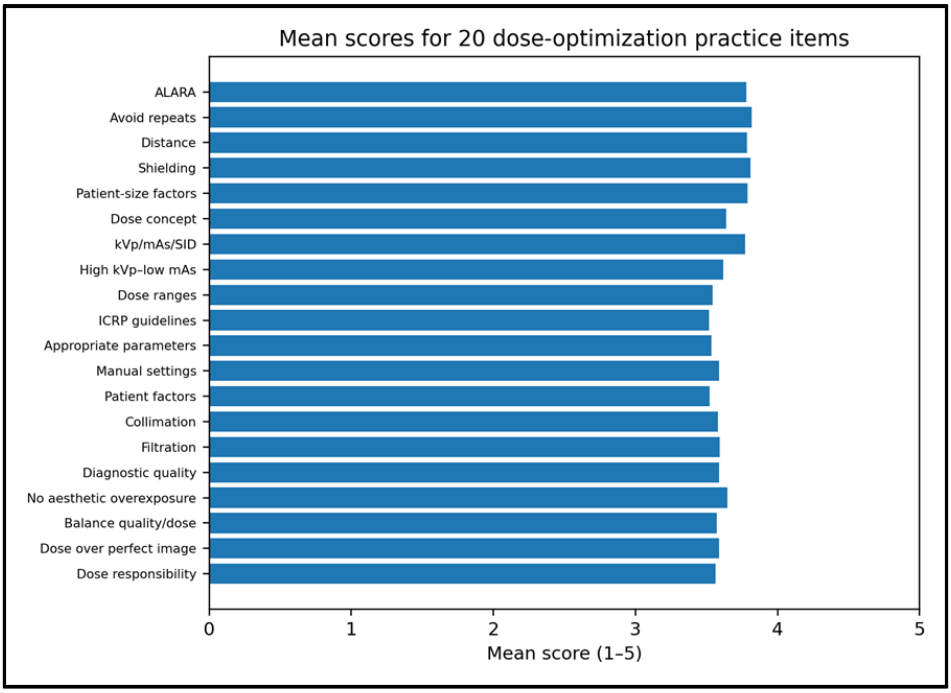


Figure 3. Mean scores for the 20 dose-optimization practice items.

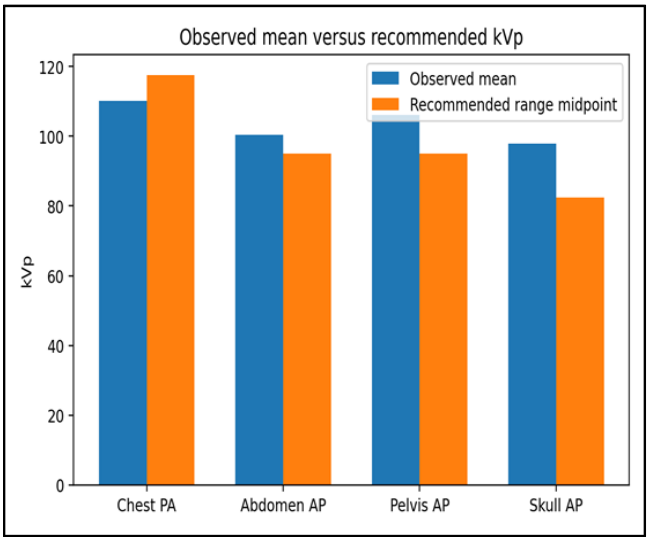


Figure 4. Observed mean versus recommended kVp

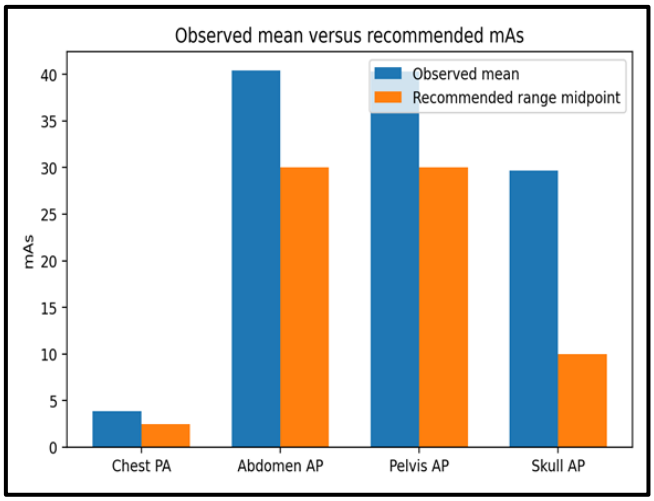


Figure 5. Observed mean versus recommended mAs

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Association with Professional Role

Professional role was significantly associated with dose-optimization grouping (Pearson χ^2=210.303, df=2, p<0.001). All 135 student radiographers were classified in the lower optimization group. Among radiology technicians, 91 (67.4%) were in the higher group and 44 (32.6%) in the lower group. Among senior radiographers, 98 (86.0%) were in the higher optimization group. The pattern indicates progressively stronger optimization practice with greater professional maturity.

Association with Professional Experience

Years of professional experience showed a strong association with dose-optimization grouping (Pearson χ^2=289.712, df=3, p<0.001). Of the 205 participants with 1–3 years of experience, 187 (91.2%) were in the lower optimization group and 18 (8.8%) were in the higher group. In contrast, 67 of 75 participants (89.3%) with 3–5 years were in the higher group. All participants with 5–10 years (n=75) and 10+ years (n=29) were classified in the higher group.

Association with Facility Type

Healthcare facility type was also significantly associated with dose-optimization grouping (Pearson χ^2=16.732, df=2, p<0.001). The study reported better optimization practice in private hospitals than in government hospitals, with diagnostic centres occupying an intermediate position. This finding suggests that institutional resources, protocols, supervision, equipment, and organizational culture may influence how optimization principles are implemented.

Table 1. Associations between participant characteristics and dose-optimization grouping.

Association	Pearson χ^2	df	p-value
Professional role × optimization group	210.303	2	<0.001
Experience × optimization group	289.712	3	<0.001
Facility type × optimization group	16.732	2	<0.001

DISCUSSION

This study found an overall dose-optimization score of 3.64 ± 0.67, suggesting that imaging professionals generally recognize and report the importance of radiation protection, but that implementation is not uniformly strong. The most encouraging finding was the high score for avoiding repeat exposures through careful positioning, while the lowest score concerned awareness of international guidelines. This distinction is important: practitioners may understand practical safety behaviors without having a strong working knowledge of DRLs, ICRP recommendations, or examination-specific reference values.

The finding is consistent with previous research showing that knowledge of radiation safety does not always translate into detailed operational competence. Zekioglu *et al*. reported that 68.6% of healthcare professionals correctly answered radiation-safety questions despite routinely working in radiation-producing environments [Zekioğlu, A., & Parlar, Ş. 2021]. Aldahery *et al*. likewise reported strong awareness of ALARA but weaker knowledge of dose-related technical measures and DRLs [Samara, E. T. *et al*., 2022]. These findings, together with the present results, indicate a need for education that moves beyond general statements about radiation hazards toward practical protocol selection and dose evaluation.

The routine exposure factors reported in the present study provide useful benchmarks. Chest PA examinations averaged 110.06 kVp and 3.85 mAs, while abdomen AP, pelvis AP, and skull AP averaged 100.42/40.41, 106.15/40.33, and 97.95/29.65 kVp/mAs, respectively. The study's comparison with recommended ranges showed broad alignment for abdomen and pelvis examinations, partial alignment for chest PA, and a notable excess in routine skull mAs. These findings should not be interpreted as direct patient-dose measurements because exposure factors alone cannot determine patient dose. Patient thickness, filtration, source-to-image distance, detector response, automatic exposure control, and equipment calibration also affect dose.

Babikir *et al*. demonstrated the importance of this broader perspective by assessing image quality and entrance-surface air kerma across ten hospitals. Their study reported considerable inter-hospital variation and found that chest examinations could have higher entrance doses than international reference levels [Steffensen, C. *et al*., 2021]. Similarly, Tsapaki emphasized that optimization requires quality assurance, measurement of current dose levels, protocol adjustment, reassessment, and staff training rather than a single change in exposure factors [Al-Othman, A. Y. *et al*., 2022].

The high endorsement of continuing training in the present study (3.80 ± 0.93) represents an important

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opportunity. Whitebird *et al*. described organizational approaches to dose optimization that included engaging radiologists and technologists, creating dose committees, monitoring and comparing dose levels, revising protocols, and improving equipment and policies. Thus, continuing professional education should be integrated with institutional systems rather than delivered only as isolated lectures.

The strong association between experience and optimization practice was one of the most prominent findings. Student radiographers were concentrated in the lower optimization group, whereas senior radiographers were predominantly in the higher group. Experience may improve practical understanding of patient positioning, exposure selection, repeat avoidance, and workflow. However, experience alone should not be assumed to guarantee optimal practice. Continuing education remains necessary because technology, detector systems, clinical protocols, and dose-management recommendations evolve.

Facility type was also significantly related to optimization. Better performance in private hospitals than government hospitals may reflect differences in equipment availability, protocol standardization, workload, quality-assurance practices, staff development, and access to dose-monitoring systems. The finding should nevertheless be interpreted cautiously because the study did not directly measure equipment performance or actual patient doses. Previous research has shown that institutional variation can influence radiation exposure and image quality, supporting the need for standardized quality-control and dose-monitoring programs [Steffensen, C. *et al*., 2021].

The results also reinforce the importance of balancing image quality and radiation dose. Optimization should not be understood as simply reducing kVp or mAs. Excessive reduction can increase noise and repeat rates, while unnecessarily high exposure may provide little clinical benefit. Digital radiography requires particular attention because post-processing can compensate for underexposure visually while failing to alert operators to excessive detector exposure. Evidence on high-kVp/low-mAs approaches and systematic exposure-factor optimization supports individualized protocols based on patient size, examination type, equipment, and clinical indication [Thakur, Y. *et al*., 2013; Tsapaki, V. *et al*., 2020].

Patient shielding should also be approached according to contemporary radiation-protection principles and local policy. A systematic review by Samara *et al*. found limited dose reduction from routine patient shielding and identified potential disadvantages in some circumstances. Therefore, optimization should prioritize justification, collimation, appropriate technique, positioning, equipment performance, and avoidance of unnecessary repeat exposures rather than relying on shielding as the primary dose-reduction strategy.

Overall, the present study adds evidence from Pakistan showing that professional role, experience, and facility type are associated with reported optimization practice. The findings support a systems-based approach involving competency-based education, standardized examination protocols, regular quality assurance, DRL awareness, audit of exposure indicators, and accessible continuing professional development.

The study relied on self-reported questionnaire responses and therefore may be affected by recall and social-desirability bias. The cross-sectional design prevents assessment of changes over time or causal relationships. Participants were recruited using non-probability sampling, and the sample may not represent all imaging professionals in Pakistan. Most importantly, actual patient doses and radiographic image quality were not measured directly. The reported kVp and mAs values therefore describe practice patterns rather than verified patient radiation doses. Future studies should combine questionnaires with dose audits, exposure-index data, image-quality assessment, equipment quality-control measurements, and longitudinal educational interventions.

CONCLUSION

Imaging professionals participating in this study demonstrated moderate overall radiation dose-optimization practice, with a mean score of 3.64 ± 0.67. Practical safety behaviors such as careful positioning and avoiding repeat exposures were relatively strong, whereas awareness of international guidelines and recommended dose ranges was weaker. Dose-optimization practice was significantly associated with professional role, years of experience, and healthcare facility type. Routine exposure factors were broadly aligned with the recommended ranges used in the study, although chest PA kVp and skull AP mAs showed areas for review. The findings indicate that patient safety can be strengthened through standardized

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protocols, continuing education, competency assessment, equipment quality control, and systematic dose monitoring.

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