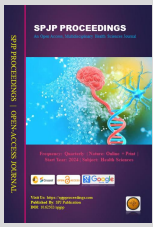


Chapter- 3.

Patient Dose Optimization Techniques in Digital Radiography: A Mini Review



Mini Review

[1]Kashish Francis, [2]Arshad Alam Khan, [3]Ashita Jain*

[1,2,3] Dept. of Radio Imaging Technology, School of Allied Health Science, SGT University, Gurugram (HR), India

ABSTRACT

Digital radiography (DR) has significantly improved diagnostic imaging through enhanced image quality, rapid image acquisition, wider dynamic range, and advanced post-processing capabilities. However, the increased flexibility of digital systems has also introduced challenges related to radiation dose management, particularly the risk of "dose creep," where excessive radiation exposure may go unnoticed due to automatic image correction. Patient dose optimization has therefore become a critical component of modern radiological practice. The primary aim of dose optimization is to achieve diagnostically adequate images while minimizing unnecessary radiation exposure in accordance with the As Low As Reasonably Achievable (ALARA) principle. This mini review discusses the major techniques and strategies used for dose optimization in digital radiography, including appropriate exposure parameter selection, Automatic Exposure Control (AEC), collimation, beam filtration, quality assurance programs, and exposure monitoring using Exposure Index (EI) and Deviation Index (DI). The review also highlights the importance of protocol-based and patient-centered optimization approaches, particularly body mass index (BMI)-based dose optimization, which allows individualized exposure selection according to patient body habitus. In addition, the role of technological advancements, professional workflow strategies, and artificial intelligence (AI)-assisted imaging in improving radiation safety is discussed. Effective dose optimization requires a combination of advanced technology, evidence-based protocols, radiographer expertise, and continuous quality improvement to ensure high-quality diagnostic imaging while maintaining patient safety.

Keywords: Digital radiography, dose optimization, ALARA, radiation protection, exposure index, deviation index, BMI-based optimization, Automatic Exposure Control, diagnostic reference levels, patient safety.

***Corresponding Author:** Ashita Jain, Assistant Professor, School of Allied Health Sciences, SGT University | **Email**: ashita_fahs@sgtuniversity.org | **DOI**: 10.62502/spjpp/v3i2art3 | **Received**: 10/01/2026 | Accepted: 15/03/2026 | Published: 25/04/2026

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INTRODUCTION

Digital radiography has revolutionized diagnostic imaging by replacing conventional film-screen radiography with advanced digital detector systems. Compared with traditional radiography, digital systems provide faster image acquisition, improved workflow efficiency, higher detector sensitivity, wider dynamic range, and enhanced post-processing capabilities. [1-3] These technological improvements have substantially improved diagnostic performance and clinical productivity in modern radiology departments. However, the transition from film-screen systems to digital radiography has also introduced new concerns regarding patient radiation exposure. In conventional film-screen radiography,

excessive exposure produced overly dark films that immediately alerted radiographers to overexposure. Digital radiography systems automatically adjust image brightness and contrast through image processing algorithms, allowing overexposed images to appear diagnostically acceptable. This phenomenon may lead to a gradual and often unnoticed increase in patient dose over time, commonly referred to as "dose creep." Patient dose optimization has therefore become an essential principle in digital imaging practice. [4-7] Dose optimization refers to obtaining the highest possible diagnostic image quality while using the minimum radiation dose necessary for adequate diagnosis. Optimization does not imply using the lowest achievable dose regardless of image quality; rather, it emphasizes balancing image quality and radiation safety. Insufficient radiation exposure results in noisy or nondiagnostic images that may require repeat examinations, whereas excessive exposure unnecessarily increases radiation risk without additional diagnostic benefit. [8-10] Modern dose optimization strategies involve a combination of radiation protection principles, advanced imaging technology, quality assurance programs, professional expertise, and patient-specific imaging approaches. Recent developments have further emphasized personalized optimization methods based on patient size, body habitus, and body mass index (BMI), recognizing that standardized exposure protocols may not be appropriate for all patients. This mini review discusses the scientific principles, techniques, technological advancements, and emerging trends involved in patient dose optimization in digital radiography.

OBJECTIVES OF PATIENT DOSE OPTIMIZATION

The primary objective of patient dose optimization is to ensure that every radiographic examination provides sufficient diagnostic information while minimizing unnecessary radiation exposure. Several important goals contribute to this objective:

Radiation Safety: One of the major goals is reducing unnecessary patient exposure to ionizing radiation. Although diagnostic radiology generally uses relatively low radiation doses, repeated exposure and the high global frequency of radiographic examinations contribute significantly to population radiation burden. Even low doses of ionizing radiation may increase stochastic risks such as carcinogenesis.

Maintenance of Diagnostic Image Quality: Optimization aims to achieve diagnostically acceptable image quality rather than simply minimizing radiation dose. Excessive dose reduction may increase image noise and reduce diagnostic accuracy, potentially leading to missed diagnoses or repeat imaging.

Reduction of Repeat Examinations: Repeat radiographs caused by positioning errors, motion artifacts, improper exposure selection, or poor collimation significantly increase patient dose. Optimization strategies aim to reduce reject and repeat rates through proper training, standardized protocols, and quality assurance.

Standardization of Imaging Practice: Dose optimization seeks to minimize variability in patient dose among different radiographers, imaging systems, and healthcare institutions. Standardized protocols and diagnostic reference levels (DRLs) promote consistent and safe imaging practices.

Patient-Specific Imaging: Modern optimization approaches recognize individual patient variability. Pediatric, geriatric, obese, pregnant, and critically ill patients require customized imaging techniques based on their anatomical and physiological characteristics.

Promotion of Radiation Safety Culture: Optimization also supports the development of a radiation safety culture involving continuous education, professional responsibility, teamwork, quality improvement, and adherence to radiation protection principles.

PRINCIPLES OF RADIATION PROTECTION

Radiation protection in diagnostic radiology is based on three fundamental principles: justification, optimization and dose limit.

Justification: Every radiographic examination must be clinically justified. The diagnostic benefit should outweigh the potential radiation risk. Unnecessary imaging contributes to avoidable patient exposure and should be avoided through adherence to evidence-based imaging guidelines.

Optimization: Optimization requires maintaining radiation exposure "As Low As Reasonably Achievable" (ALARA) while preserving adequate image quality. This principle forms the foundation of modern dose management strategies in digital radiography.

Dose Limitation: Dose limits primarily apply to occupational and public exposure rather than medical exposure. Since patient imaging provides direct medical benefit, strict dose limits are not applied; therefore, optimization becomes the principal method of patient protection.

METHODS OF DOSE OPTIMIZATION IN DIGITAL RADIOGRAPHY

Exposure Parameter Selection: Selection of appropriate exposure parameters plays a major role in dose optimization.

Effect of kVp and mAs: Tube voltage (kVp) controls beam energy and penetration, whereas milliampere-seconds (mAs) determine photon quantity. Higher kVp techniques combined with lower mAs may reduce patient dose for examinations such as chest radiography by increasing beam penetration while reducing absorbed dose. However, excessively high kVp may reduce image contrast. Lower mAs reduces patient dose but increases image noise. Therefore, careful balancing of kVp and mAs according to patient size and anatomical region is essential. [12-15]

Automatic Exposure Control (AEC): AEC systems automatically terminate exposure when sufficient radiation reaches the detector. Proper use of AEC improves exposure consistency and reduces unnecessary dose variation among patients. Incorrect chamber selection, improper patient positioning, or poor collimation may lead to overexposure or underexposure. Regular calibration and quality control testing are essential for optimal AEC performance.

Collimation: Collimation restricts the X-ray beam to the anatomical region of interest. Proper collimation leads to Reduces irradiated tissue volume, Lowers scatter radiation, Improves image contrast, Decreases patient dose. Inadequate collimation unnecessarily increases radiation exposure and may reduce image quality.

Beam Filtration: The X-ray beam contains low-energy photons that contribute to patient skin dose without improving image formation. Additional filtration using aluminum or copper removes low-energy photons from the beam, thereby reducing unnecessary radiation exposure while maintaining image quality.

Quality Control and Equipment Calibration: Regular quality assurance programs are essential for dose optimization. Equipment testing ensures: Accurate kVp output, Stable tube current, Correct exposure timing, Proper AEC performance.

Detector consistency: Improperly calibrated equipment may increase patient dose or produce poor-quality images requiring repetition.

Radiographer Training and Education: Radiographers play a critical role in optimization. Professional knowledge regarding, Exposure selection, Radiation biology, Detector technology, Positioning techniques, Exposure index interpretation, Patient communication, directly influences patient dose and image quality.

Continuous professional education remains essential due to ongoing technological advancements.

EXPOSURE INDEX (EI) AND DEVIATION INDEX (DI)

Exposure monitoring is an essential component of digital radiography optimization.

Exposure Index (EI): Exposure Index represents the quantity of radiation reaching the digital detector. It provides feedback regarding detector exposure and assists radiographers in evaluating exposure adequacy. Different manufacturers previously used non-standardized exposure indicators, creating confusion in clinical practice. International standardization efforts have improved consistency in EI interpretation. An excessively high EI may indicate overexposure, whereas a very low EI suggests underexposure and increased image noise. [11-13]

Deviation Index (DI): Deviation Index compares the actual exposure index with the target exposure index.

$$DI = 10\log_{10}\frac{EI}{EI_T}$$

Where:

- EI = measured exposure index
- EIT = target exposure index

A DI value of:

- 0 indicates ideal exposure
- Positive values indicate overexposure
- Negative values indicate underexposure

Routine monitoring of EI and DI helps identify dose creep and supports optimization programs.

TYPES OF DOSE OPTIMIZATION

Dose optimization in digital radiography can be classified into several categories based on the methods used to reduce radiation exposure while maintaining adequate diagnostic image quality.

These approaches collectively contribute to safer imaging practices and improved patient care. Technique-based optimization involves modifying radiographic exposure parameters according to the examination type and individual patient characteristics. Important technical factors include tube voltage (kVp), milliampere-seconds (mAs), exposure time, focal spot size, and grid usage. Appropriate adjustment of these parameters helps achieve an optimal balance between image quality and patient dose. For example, higher kVp with lower mAs may be used in chest radiography to reduce radiation exposure, while lower kVp techniques may be preferred for extremity imaging to improve image contrast. Similarly, minimizing exposure time reduces motion blur and decreases the likelihood of repeat examinations. [14,15] Technology-based optimization focuses on the use of advanced imaging technologies that support dose reduction. Modern digital radiography systems incorporate Automatic Exposure Control (AEC) systems, high detective quantum efficiency (DQE) detectors, beam filtration devices, dose modulation software, advanced image processing algorithms, and iterative reconstruction techniques. These technologies improve detector efficiency, reduce image noise, and enable the production of diagnostically acceptable images at lower radiation doses. AEC systems automatically terminate exposure once sufficient radiation reaches the detector, thereby reducing the risk of overexposure and improving consistency in image acquisition.

Protocol-based optimization refers to the development and implementation of standardized imaging protocols within radiology departments. These protocols are established using diagnostic reference levels (DRLs), local dose audits, and evidence-based clinical guidelines. Standardization helps reduce variations in exposure practices among radiographers and institutions, ensuring consistent image quality and radiation safety. Regular review and updating of protocols based on audit findings and technological advancements further enhance optimization practices. Patient-based optimization involves tailoring exposure parameters according to patient-specific factors such as age, body habitus, clinical condition, and radiation sensitivity. Different patient groups require individualized imaging approaches to avoid unnecessary radiation exposure. Paediatric patients, for example, are more sensitive to ionizing radiation and therefore require significantly lower exposure settings than adults. Similarly, elderly, pregnant, and critically ill patients may require modified imaging techniques to ensure both safety and diagnostic accuracy.

BMI-based dose optimization represents an emerging patient-centered approach that uses body mass index (BMI) as a guide for selecting appropriate exposure parameters. BMI is calculated as:

$$\text{BMI}=\frac{Weight\ (kg)}{Height\ (m2)}$$

BMI correlates with patient body thickness and tissue attenuation, both of which significantly influence radiation absorption and image quality. Standardized exposure techniques may lead to overexposure in underweight patients and underexposure in obese patients, resulting in inconsistent image quality and increased repeat examinations. To address this issue, BMI-based benchmark doses (BMDs) classify patients into categories such as underweight, normal weight, overweight, and obese. Exposure parameters are then adjusted according to these categories to achieve more individualized imaging. Studies have shown that BMI-based optimization improves image consistency, reduces repeat rates, and supports the ALARA principle more effectively than fixed exposure protocols.

TECHNOLOGICAL SUPPORT FOR DOSE OPTIMIZATION

Modern digital radiography systems provide numerous technological tools that support optimization.

High DQE Digital Detectors: High detective quantum efficiency detectors convert incoming radiation into image signal more efficiently, enabling lower radiation exposure while maintaining image quality.

Advanced Image Processing: Noise reduction algorithms and iterative reconstruction methods improve image quality at reduced exposure levels.

Dose Monitoring Software: Dose tracking systems continuously monitor patient exposure indices and compare them with diagnostic reference levels. These systems facilitate:

- Audit programs
- Quality improvement

- Identification of dose trends
- Detection of dose creep

Artificial Intelligence (AI): AI-assisted systems are increasingly used for:

- Automated exposure selection
- Patient size estimation
- Real-time optimization
- Image quality analysis

Future AI systems may integrate patient anatomy, BMI, prior imaging data, and DRLs to provide fully personalized exposure protocols.

PROFESSIONAL PRACTICE AND WORKFLOW STRATEGIES

Professional practice and workflow management play a crucial role in patient dose optimization in digital radiography. Even with advanced imaging technology, improper radiographic techniques and poor workflow practices can increase patient radiation exposure and compromise image quality. Therefore, radiographers and imaging professionals must integrate proper positioning, effective communication, quality assurance practices, and radiation safety principles into routine clinical practice. Accurate patient positioning is one of the most important components of dose optimization. Proper positioning ensures that the anatomical area of interest is correctly visualized during the first exposure, thereby minimizing the need for repeat examinations. Incorrect positioning may result in image distortion, anatomical cut-off, or poor visualization of clinical findings, all of which can necessitate additional exposures and increase patient radiation dose. Careful alignment of the patient, image receptor, and X-ray beam therefore contributes significantly to both image quality and radiation safety. Effective patient communication also plays a major role in reducing unnecessary radiation exposure. Clear instructions regarding breath-holding, body movement, and examination procedures help minimize motion artifacts that may degrade image quality.

In pediatric, elderly, or critically ill patients, proper immobilization techniques and reassurance are particularly important to prevent motion-related repeats. Good communication not only improves examination efficiency but also enhances patient cooperation and comfort during imaging procedures. Collimation and shielding remain important aspects of radiation protection. Modern recommendations increasingly emphasize precise collimation rather than routine shielding practices. Restricting the X-ray beam strictly to the area of clinical interest reduces unnecessary irradiation of surrounding tissues, decreases scatter radiation, and improves image contrast. Excessively large radiation fields unnecessarily increase patient dose and may reduce image quality. Although shielding was traditionally used to protect radiosensitive organs, recent evidence suggests that improper shielding may interfere with Automatic Exposure Control (AEC) systems, obscure important anatomical structures, and occasionally increase patient dose. Consequently, optimization strategies now focus more strongly on appropriate exposure selection and accurate collimation.

Reject analysis programs are another essential workflow strategy for dose optimization. Regular evaluation of rejected and repeated images helps identify common technical errors such as improper exposure selection, positioning mistakes, motion artifacts, or collimation errors. By analyzing repeat patterns, radiology departments can implement targeted radiographer training and protocol modifications to reduce unnecessary exposures. Continuous monitoring of reject rates also supports quality improvement initiatives and promotes more consistent imaging practices.

A strong radiation safety culture is fundamental for successful dose optimization in digital radiography. Effective optimization requires institutional commitment to continuous learning, quality improvement, team collaboration, and evidence-based practice. Radiographers, radiologists, medical physicists, and healthcare administrators must work together to maintain safe imaging environments and ensure adherence to radiation protection principles. Ongoing professional education, regular quality assurance programs, and active participation in dose monitoring initiatives further strengthen radiation safety practices and contribute to improved patient care.

Future Perspectives: The future of dose optimization lies in personalized and technology-driven imaging approaches. AI-assisted exposure selection, automated dose monitoring systems, adaptive imaging protocols, and patient-specific benchmark doses are expected to further improve safety and efficiency. Precision radiology

approaches integrating BMI, body composition, anatomy recognition, and clinical indication may soon allow truly individualized imaging protocols.

CONCLUSION

Patient dose optimization in digital radiography is a multidimensional process involving radiation protection principles, technological advancements, professional expertise, and patient-centered imaging strategies. The transition to digital imaging has improved diagnostic capabilities but also introduced challenges such as dose creep and exposure variability. Optimization requires careful selection of exposure parameters, effective use of AEC, proper collimation, beam filtration, quality assurance programs, and continuous radiographer education. Monitoring tools such as Exposure Index (EI) and Deviation Index (DI) are essential for identifying exposure trends and maintaining safe imaging practice. Emerging BMI-based benchmark dose approaches represent an important advancement toward individualized radiography, improving both image quality consistency and patient safety.

DECLARATION

The authors declare that this manuscript is original and has not been published previously nor is it under consideration for publication elsewhere. All authors have made substantial contributions to the conception, design, literature review, drafting, and revision of the manuscript and have approved the final version for publication. The authors further declare that there is no conflict of interest related to this work. No financial support or sponsorship was received for the preparation of this article. All information included in this review has been appropriately cited and referenced according to academic and ethical publishing standards.

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