

Optimizing Diagnostic Radiation Dose in Digital Radiography

Physics Foundations, Exposure Indicators, Protocol Tailoring, and Deep-Learning Reconstruction

Leo A. Jiwanmall, MBA, PMP®, MRSO®, R.T.(R)(MR)(CT)

Founder, Imaging Informatics Hub

White Paper

Version 1.0

October 2026

Imaging Informatics Hub

LeoJiwanmall.com

© 2026 Leo A. Jiwanmall. All rights reserved.

Abstract

Digital radiography (DR) and computed radiography (CR) have transformed diagnostic imaging through wide dynamic-range detectors, advanced post-processing techniques, and improved clinical workflow efficiency. While these technologies have reduced repeat examinations and enhanced image acquisition flexibility, they have also introduced the risk of dose creep, whereby patient radiation exposure gradually increases because excessive detector exposure is no longer visually apparent.

This white paper examines practical strategies for optimizing radiation dose while preserving diagnostic image quality. Key topics include detector efficiency, image noise mechanics, exposure indicator monitoring, beam filtration, technique optimization, diagnostic reference levels (DRLs), and emerging deep-learning reconstruction methods. The aim is to provide radiologic technologists, imaging leaders, medical physicists, and healthcare organizations with evidence-based approaches for maintaining ALARA principles while supporting clinical confidence and diagnostic accuracy.

Author Information

Leo A. Jiwanmall, MBA, PMP®, MRSO®, R.T.(R)(MR)(CT)

Founder, Imaging Informatics Hub

Leo A. Jiwanmall is an Imaging Informatics professional specializing in PACS administration, DICOM integration, MRI safety, medical imaging sciences, healthcare technology, and project management.

Keywords: Digital Radiography, ALARA, Dose Optimization, Exposure Indicator, Deviation Index, Detective Quantum Efficiency (DQE), PACS, Imaging Informatics, MRI Safety, Artificial Intelligence, Deep Learning Reconstruction, Radiation Physics.

Executive Summary

Digital radiography has fundamentally changed the practice of diagnostic imaging. Modern detectors provide exceptional flexibility and image quality; however, the removal of visual indicators of overexposure has made radiation dose management increasingly dependent on exposure monitoring, quality assurance processes, and technologist expertise.

Maintaining optimal image quality while minimizing patient dose requires a multifaceted strategy. These strategies include:

- Routine monitoring of Exposure Indicators (EI) and Deviation Index (DI) values
- Optimization of detector utilization through high-DQE systems
- Strategic use of copper filtration and high-kVp techniques
- Routine comparison of local protocols against Diagnostic Reference Levels (DRLs)
- Careful adoption of advanced deep-learning denoising and reconstruction technologies

By combining detector physics, exposure monitoring, protocol optimization, and emerging artificial intelligence tools, imaging departments can continue to improve image quality while reducing unnecessary patient radiation exposure.

1. Introduction & Clinical Background

The transition from screen-film radiography to digital radiography (DR) and computed radiography (CR) fundamentally changed daily imaging workflows.

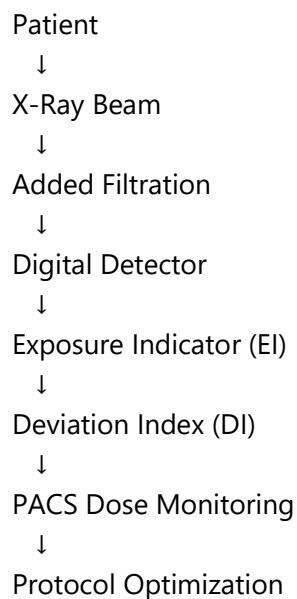
In the film era, image exposure was self-limiting. Overexposing a film cassette resulted in a dark, unusable image, providing immediate feedback when technical factors were excessive.

Digital detectors operate over a substantially wider dynamic range and utilize sophisticated post-processing algorithms to normalize image brightness and contrast. While this flexibility minimizes repeat imaging due to exposure errors, it also removes the visual warning signs that historically helped technologists recognize excessive exposure.

An overexposed digital image often appears visually pleasing because increased detector exposure improves signal-to-noise ratio and reduces quantum mottle. Over time, this can lead to a gradual increase in departmental exposure techniques, commonly referred to as **dose creep**.

Because every radiation exposure should be justified and optimized, a thorough understanding of detector physics, imaging protocols, and exposure monitoring remains essential to maintaining radiation doses As Low As Reasonably Achievable (ALARA).

Figure 1. Digital Radiography Dose Optimization Workflow



2. Detector Physics and Noise Mechanics

Optimizing radiographic technique requires understanding how detectors convert x-ray photons into diagnostic image information and where image noise originates.

The fundamental measure of detector performance is **Detective Quantum Efficiency (DQE)**:

$$DQE(f) = \frac{SNR_{out}^2(f)}{SNR_{in}^2(f)}$$

DQE quantifies how efficiently an imaging system converts incoming photon information into useful image signal.

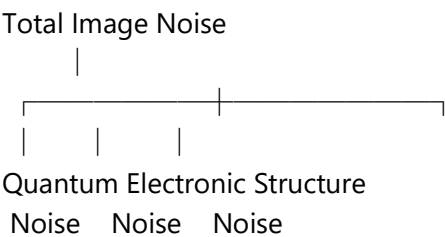
Modern flat-panel detectors using Cesium Iodide (CsI) or amorphous Selenium (a-Se) exhibit substantially higher DQE than conventional computed radiography systems, enabling diagnostic imaging at lower radiation exposures.

Despite advances in detector technology, image quality remains influenced by several sources of noise.

Table 1. Sources of Image Noise

Noise Type	Source	Controlled by Technologist?
Quantum Noise	Statistical variation in photon detection	Yes
Electronic Noise	Detector electronics and signal readout	No
Structure Noise	Physical characteristics of the detector	No

Figure 2. Components of Digital Radiography Noise



In clinical practice, quantum noise is the primary factor controlled by technique selection.

Excessive reductions in mAs increase photon starvation, resulting in a grainy appearance commonly referred to as quantum mottle.

While image-processing software can improve image appearance, lost anatomical information cannot be recreated after acquisition. The objective is not achieving the lowest possible dose, but rather achieving the lowest dose capable of producing a diagnostic image.

3. Exposure Indicators and Deviation Index Protocols

Historically, digital imaging manufacturers used proprietary exposure indices, making exposure assessment difficult across different systems.

To standardize exposure monitoring, the International Electrotechnical Commission (IEC 62494-1) and AAPM Task Group 116 established a common framework based on:

- Exposure Indicator (EI)
- Target Exposure Indicator (EIT)
- Deviation Index (DI)

The Exposure Indicator represents detector exposure for a defined clinical image region.

The Deviation Index is calculated as:

$$DI = 10 \times \log_{10} \left(\frac{EI}{EI_T} \right)$$

A DI value of zero indicates that detector exposure matched the established target.

Figure 3. Deviation Index Interpretation

DI						
-3	-2	-1	0	+1	+2	+3
----- ----- ----- ----- ----- -----						
Severe	Under	Slight	Ideal	Slight	Over	Excessive
Under	Expo.	Under		Over		

Table 2. Recommended Deviation Index Actions

DI Range	Interpretation	Recommended Action
> +3	Significant overexposure	Review technique factors; avoid repeats unless detector saturation occurred
+1 to +3	Mild overexposure	Reduce exposure techniques if trend persists
-1 to +1	Target range	No action required
-3 to -1	Mild underexposure	Assess image for quantum mottle
< -3	Significant underexposure	Consider repeat only if image is nondiagnostic

A critical ALARA principle is recognizing that an overexposed image should rarely be repeated solely because the DI exceeds target values. Repeating the study only compounds patient dose. Instead, technical factors should be adjusted for future examinations.

4. Radiographic Technique Optimization and Protocol Tailoring

Exposure monitoring provides valuable feedback, but protocol design remains the primary method of minimizing unnecessary radiation exposure.

4.1 Spectral Shaping and Added Copper Filtration

A significant portion of the x-ray spectrum consists of low-energy photons that contribute little to image formation while increasing patient skin dose.

Added copper filtration removes these low-energy photons before they reach the patient, hardening the beam and improving spectral efficiency.

Common configurations include:

- 0.1 mm Cu + 1.0 mm Al
- 0.2 mm Cu + 1.0 mm Al
- 0.3 mm Cu + 1.0 mm Al

Copper filtration has demonstrated meaningful reductions in entrance skin dose, particularly in pediatric and extremity imaging.

4.2 High-kVp Techniques and the 15% Rule

Modern digital detectors tolerate higher kVp techniques more effectively than traditional screen-film systems.

Applying the 15% Rule allows technologists to increase kVp while reducing mAs, maintaining detector exposure while lowering overall patient dose.

Benefits include:

- Reduced patient absorption
 - Improved beam penetration
 - Lower technique requirements
 - Reduced overall patient dose
-

4.3 Diagnostic Reference Levels and Departmental Audits

Diagnostic Reference Levels (DRLs) provide benchmark values for evaluating imaging practices at the facility level.

DRLs are not dose limits. Instead, they serve as investigation thresholds that help identify protocols warranting review and optimization.

Facilities should routinely compare local exposure metrics against:

- National DRLs
- State benchmarks
- Professional registry data
- Institutional quality assurance programs

Table 3. Example Dose Optimization Strategies

Strategy	Mechanism	Clinical Benefit
High-DQE Detectors	Improved detector efficiency	Lower required exposure
Copper Filtration	Removes non-diagnostic photons	Reduced skin dose
High-kVp Techniques	Improved beam transmission	Lower absorbed dose
DI Monitoring	Exposure standardization	Prevents dose creep
AI Denoising	Improved image quality at lower exposures	Potential dose reduction

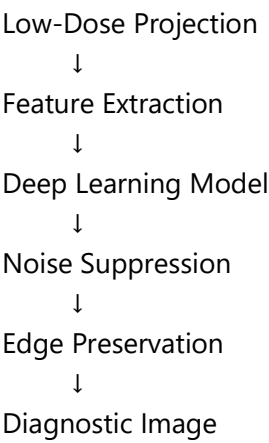
Illustrative examples only. Facilities should reference locally adopted DRLs and regulatory guidance when performing dose audits.

5. Deep-Learning Image Reconstruction and AI Denoising

Artificial Intelligence (AI) represents one of the most promising developments in digital radiography dose optimization.

Traditional noise-reduction algorithms often reduce image noise at the expense of image sharpness. Deep-learning reconstruction approaches utilize large training datasets to learn distinctions between image noise and anatomical structures.

Figure 4. Deep-Learning Reconstruction Workflow



By selectively suppressing noise while preserving anatomical detail, these technologies may allow meaningful exposure reductions while maintaining diagnostic confidence.

Published studies have demonstrated promising results; however, achievable dose reductions vary by anatomy, detector technology, clinical workflow, reconstruction algorithm, and diagnostic task.

AI should be viewed as an enhancement to established radiographic principles rather than a substitute for proper positioning, collimation, exposure selection, and image evaluation.

Key Recommendations

For Radiologic Technologists

- Monitor Deviation Index values routinely.
- Avoid unnecessary image repeats based solely on exposure indicator deviations.
- Utilize appropriate collimation and beam restriction.
- Apply high-kVp techniques when clinically appropriate.
- Understand protocol-specific target EI values.

For Imaging Departments

- Perform routine exposure indicator audits.
- Benchmark imaging performance against established DRLs.
- Review outlier protocols regularly.
- Standardize exposure indicator targets across systems.

For Medical Physicists and Imaging Leaders

- Validate exposure indicator calibration.
 - Monitor departmental dose trends.
 - Support evidence-based protocol optimization.
 - Evaluate emerging AI reconstruction technologies critically.
-

Conclusion

Dose optimization in digital radiography requires a continuous balance between diagnostic image quality and patient safety.

Modern detectors, advanced post-processing systems, and AI-driven reconstruction tools have expanded the capabilities of diagnostic imaging, but they have also increased the importance of exposure monitoring and protocol management.

Exposure Indicator and Deviation Index programs provide practical safeguards against dose creep, while spectral shaping, high-kVp techniques, and departmental dose audits support broader optimization efforts.

Ultimately, technology alone cannot ensure ALARA compliance. The radiologic technologist remains the most important factor in dose management, applying technical expertise, sound judgment, and clinical experience to ensure every examination delivers maximum diagnostic value at the lowest reasonable radiation dose.

References

American Association of Physicists in Medicine. (2009). *An Exposure Indicator for Digital Radiography (AAPM Task Group Report 116)*. AAPM.

Brosii, K., Lanza, C., & Herrmann, T. (2021). Optimization of radiation dose and image quality using added copper filtration in pediatric digital radiography. *Journal of Medical Imaging and Radiation Sciences*, 52(3), 341-349.

Bushberg, J. T., Seibert, J. A., Leidholdt, E. M., & Boone, J. M. (2020). *The Essential Physics of Medical Imaging* (4th ed.). Lippincott Williams & Wilkins.

Davidson, R. (2020). Dose creep in digital radiography. In C. Hayre & W. Cox (Eds.), *General Radiography: Principles and Practice* (pp. 59-69). CRC Press.

Don, S., Macdougall, R., Strauss, K., Moore, N. T., & Seibert, J. A. (2012). Image Gently campaign back to basics initiative: Ten steps to help manage radiation dose in pediatric digital radiography. *American Journal of Roentgenology*, 199(2), 481-487.

International Commission on Radiological Protection (ICRP). (2017). *Diagnostic Reference Levels in Medical Imaging (ICRP Publication 135)*. *Annals of the ICRP*, 46(1), 1-144.
<https://doi.org/10.1177/0146645317717209>

International Electrotechnical Commission (IEC). (2008). *Medical Electrical Equipment - Exposure Index of Digital X-Ray Imaging Systems - Part 1: Definitions and Requirements for General Radiography (IEC 62494-1)*. IEC.

National Council on Radiation Protection and Measurements. (2019). *Medical Radiation Exposure of Patients in the United States (NCRP Report No. 184)*. NCRP.

Seibert, J. A., & Morin, R. L. (2011). The deviation index: Understanding its meaning and application in the clinical environment. *Journal of the American College of Radiology*, 8(2), 139-140.

Shepard, S. J., Wang, J., Flynn, M., Gingold, E., Goldman, L., Krugh, K., Leong, D. L., Mah, E., Ogden, K., Peck, D., Samei, E., & Willis, C. E. (2009). An exposure indicator for digital radiography: AAPM Task Group 116 (Executive Summary). *Medical Physics*, 36(7), 2898-2914.

Sollini, M., Antunovic, L., Chiti, A., & Kirienko, M. (2019). Towards clinical application of image processing and machine learning for dose reduction in digital projection radiography. *European Journal of Radiology*, 118, 124-132.