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ALARA PRINCIPLE IN DIAGNOSTIC RADIOLOGY PRACTICE: A REVIEW STUDY

Ritam Mohapatra[1*], Kaushik Kumar Dash[2], Pritee Prachee Pradhan[3]

[1*]Assistant Professor, Nootan Institute of Allied & Health Sciences, Sankalchand Patel University, Gujarat.
mohapatraritam29@gmail.com

[2]Assistant Professor, Alard School of Allied Health Sciences, Alard University, Pune.
dashkaushikkumar@gmail.com

[3]Assistant Professor, Alard School of Allied Health Sciences, Alard University, Pune.
pracheepritee@gmail.com

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Abstract
Diagnostic radiology is based on the As Low As Reasonably Achievable (ALARA) principle that ensures the least radiation exposure to a patient and adequate diagnosis. This review paper focuses on the application of the ALARA principle in conventional radiography, computed tomography (CT), fluoroscopy and interventional radiology with particular emphasis on patient-centered dose optimization and occupational radiation safety. Methods We searched PubMed, Google Scholar, and ScienceDirect for relevant peer-reviewed articles published in English from 2000 onwards. The review discusses some of the main principles related to radiation protection—justification, optimization and dose limitation—in order to understand how unnecessary radiation exposures can be reduced. It also discusses its association with technical advancement and advances in digital radiography, automatic exposure control, iterative reconstruction, artificial intelligence, and dose monitoring systems to aid ALARA implementation. Customizable protocols are especially relevant in the field of pediatric imaging and other sub-populations who are radiosensitive, where flexibility based on risks may be necessary due to clinical findings. In addition, the review highlights that quality assurance programs, ongoing professional educational updates and collaboration of healthcare providers along with national institutional guidelines geared toward safe imaging are essential. In conclusion, the correct implementation of ALARA improves patient and occupational safety so that diagnostic accuracy is preserved and the quality of radiological services increases

Keywords: ALARA principle, Diagnostic radiology, Radiation protection, Dose optimization, Computed tomography (CT), Digital radiography, Fluoroscopy, Radiation safety, Image quality, Pediatric imaging.

Introduction

Diagnostic radiology forms a critical part of contemporary clinical practice, contributing to the diagnosis and management of many illnesses and following trends over long periods. Conventional X-ray, fluoroscopy and computed tomography (CT) are imaging techniques that supply clinicians with high anatomical detail so that they make informed clinical decisions in an effort to improve patient outcomes. In spite of these important clinical advantages, these modalities are associated with the use of ionizing radiation which is capable of harmful biological effects when exposure is either inadvertent or excessive[1] Medical radiation raises the potential for stochastic effects, notably excess lifetime cancer risk in which the likelihood of occurence tends to increase as dose increases with no threshold present. This is why provision of radiation protection, a basic principle of diagnostic imaging has evolved into practice to provide the benefit from clinical use in radiological examinations with minimum possible detriment to both patients and healthcare workers. The concept of As Low as Reasonably Achievable (ALARA) is the basis of radiation protection practices in diagnostic radiology. ALARA (as low as reasonably achievable) means not only the lowering of radiation exposure to a lowest possible level but achieving minimum dose while obtaining images accurately required for an adequate diagnostic quality. Appropriate justification of examination, optimization of imaging protocols, implementation of advanced technology and provision with appropriate protective measures for effective patient care while adhering to high standards of radiation safety.[2] Historically, ALARA emerged from growing awareness of radiation hazards and the need to enforce dose control standards in clinical settings. Early discussions emphasized regulatory enforcement and practical application in dental and medical radiography.[3] Over time, technological developments have enabled better control of exposure parameters, improving the balance between radiation dose and diagnostic image quality.[4] In CT imaging, for example, patient-specific dose estimation methods have been developed to refine exposure levels according to body size and clinical indication.[5]

In paediatric imaging, where tissues are more radiosensitive and lifetime risk is proportionally higher, strict adherence to ALARA is especially critical. Clinical evidence demonstrates that the combined application of justification and optimization significantly reduces unnecessary CT examinations and associated radiation exposure in children.[6] Similarly, healthcare systems have implemented institutional strategies to standardize dose monitoring and protocol optimization as part of comprehensive radiation safety programs.[7] The application of ALARA also extends beyond diagnostic departments to intraoperative and interventional settings. In orthopaedic procedures using fluoroscopy, adherence to ALARA has been shown to reduce occupational exposure through protective equipment use, exposure time minimization, and distance optimization.[8] Education and structured safety training further reinforce safe radiation practices among healthcare professionals.[9] While the ALARA principle is generally assumed to represent the basis of radiation protection in diagnostic imaging, its implementation has been a matter of continuing scientific controversy. The main issue being debated is whether or not any amount of ionizing radiation, no matter how small, increases the risk of cancer (the Linear No-Threshold or LNT hypothesis). Supporters of this approach argue that the hazards of radiogenic cancer at very low radiation doses have been exaggerated and that improved prognosis for patients could be lost to delays in clinically justified imaging procedures, unnecessary repetition of poorly-performed studies, or avoidance of otherwise appropriate tests. These practices can unconsciously reduce diagnostic accuracy and impair patients' management. Nevertheless, both of these contrasting perspectives continues to support the ALARA principle as a pragmatic and ethically defensible paradigm for radiation protection among most medical organizations as well as regulatory bodies. The rule focuses on dose optimization, or making sure the right amount of radiation is used rather than the lowest level of it, while still giving enough quality for a correct diagnosis. While lower-dose CT images are attractive, if the image quality is inadequate, it may lead to missed diagnoses, repeat examinations, and a higher cumulative radiation dose.[10]

Although ALARA has been implemented in technology, advances in imaging technologies have made it even easier to apply and follow this principle. With the advancement of digital radiography systems, automatic exposure control (AEC), iterative reconstruction algorithms in computed tomography (CT), artificial intelligence-assisted image processing, and real-time dose monitoring software, health-care professionals can generate diagnostic images at substantially lower radiation doses. Standardized imaging protocols, continuous quality assurance programs, and routine refresher courses designed for radiologists and radiologic technologists further ensure that all healthcare facilities employ methods of optimizing dose consistent with a practice in radiation protection. Extensive reviews have already shown that multi-disciplinary involvement of radiologists, medical physicists, radiologic technologists and healthcare administrators is essential for success in implementing ALARA.[11] With the advent of personalized imaging protocols, machine learning-based dose prediction models and automated exposure optimization systems, we expect that future advancements will continue to improve patient safety whilst preserving diagnostic efficiency. Thus, while the debate on low-dose radiation risk models continues, the ALARA philosophy remains an essential part of contemporary diagnostic radiology by balancing maximizing clinical benefit with unnecessary patient exposure to radiation. The ALARA principle is the bedrock of radiation protection in diagnostic radiology. The implementation of this solution relies on multidisciplinary coordination including radiologists, technologists, medical physicists and healthcare administrators. By continuingly improving protocols, educating health professionals and developing new technologies, ALARA guarantees that diagnostic imagery will continue to be an effective clinical tool and that diagnostic imaging will be the most safe for patients and occupationally a high standard of care.[12]

Aims

To review the application of the ALARA principle in diagnostic radiology to reduce radiation exposure while maintaining image quality and safety.

Objectives:

- To examine the fundamental principles of radiation protection, including justification, optimization, and dose limitation, in diagnostic radiology practice.
- To evaluate the role of the ALARA principle in minimizing radiation exposure across different imaging modalities such as radiography, fluoroscopy, and computed tomography (CT).
- To analyse the importance of ALARA in special populations, particularly pediatric patients, who are more sensitive to ionizing radiation.
- To explore the impact of education, training, and institutional protocols on improving radiation safety practices.

Materials and Methods

A literature review was conducted using electronic databases including PubMed, Google Scholar, and ScienceDirect. Relevant articles were identified using keywords such as “ALARA,” “radiation protection,” “dose optimization,” and “diagnostic radiology.”
Studies were screened based on titles and abstracts, followed by full-text review to ensure relevance. Only peer-reviewed articles focusing on the application of the ALARA principle in diagnostic imaging were included.

Inclusion Criteria

- Studies related to ALARA in diagnostic radiology
- Articles on radiation dose optimization and safety
- Studies involving X-ray, CT, and fluoroscopy
- Peer-reviewed articles published in English

Exclusion Criteria

- Non-English articles
- Article before 2000

Discussion

Evolution and Clinical Significance of the ALARA Principle in Diagnostic Radiology

The rapid evolution of diagnostic imaging is revolutionizing modern healthcare system with early disease detection, accurate diagnosis and image-guided therapeutic management. Radiographic examinations are the most frequently performed imaging examination, but generalization of radiological examinations brings increased exposure to ionizing radiation for both patients and healthcare workers. Though, the radiation doses used in diagnostic imaging are low the sum of multiple examinations has raised concerns about possible biological effects. Such concerns necessitated the development and continuous improvement of radiation protection strategies, with the ALARA (As Low As Reasonably Achievable) principle still representing the prevailing framework for dose optimization.[13]
ALARA is predicated upon the idea that radiation dose should be kept as low as reasonably achievable while maintaining image quality. The principle aims to achieve an optimal balance between radiation exposure and diagnostic outcome rather than merely reducing doses. This balance is imperative especially because poor image quality resulting from over dose-reduction can lead to misdiagnosis, repeat examinations, or delayed clinical decision-making in a way that increases the patient cumulative radiation burden[14] Since the widespread introduction of digital imaging technologies following conventional film-screen radiography, the ALARA principle has experienced evolution in its implementation. It's True: Modern digital detectors have

much higher detective quantum efficiency, allowing clinically acceptable image quality to be obtained at lower levels of radiation than earlier imaging systems. Such advances in technology have allowed radiology to formulate unique exposure protocols for varied patient types and clinical indications. Additionally, automatic exposure control systems that continuously adjust exposure parameters to patient thickness and anatomical region increase operator-independent reproducibility of radiation delivery and aid in the avoidance of unnecessary radiation exposure.[15] Another important development supporting ALARA implementation is the establishment of Diagnostic Reference Levels (DRLs). DRLs serve as practical dose benchmarks for common radiological examinations and help healthcare institutions identify procedures associated with unusually high radiation doses.[16] Unlike regulatory dose limits, DRLs function as optimization tools that encourage continuous evaluation of imaging protocols and equipment performance. Studies have demonstrated that routine comparison of institutional doses with national and international DRLs contributes to significant reductions in patient radiation exposure while maintaining diagnostic image quality.[17] Quality assurance programs also represent an essential component of ALARA implementation. Regular equipment calibration, detector performance testing, exposure parameter verification, and image quality assessment ensure that imaging systems operate efficiently and consistently.[18] These programs reduce technical errors, minimize repeat examinations, and improve overall patient safety. In addition, continuous auditing of radiation dose indices allows radiology departments to identify trends, implement corrective actions, and monitor compliance with established radiation protection standards.[19] Education and competency have similar impact on ALARA practice success. A thorough understanding of radiation biology and techniques for assessing dose optimization, as well as equipment capabilities, is essential for radiologists, radiologic technologists, and medical physicists. Continuing professional development has been demonstrated to enhance selective protocol choice, improve understanding of patient-specific dose modification protocols and encourage appropriate use of shielding and positioning methods. This kind of multidisciplinarity has benefits for the cultural aspects of radiation safety and improves overall the quality of diagnostics imaging services.[20] The growing complexity of imaging procedures has also underscored the need for tailored dose management. Various factors including the age of the patient, body habitus, clinical indication and imaging history should be taken into account when choosing examination protocols. Personalization of these dose optimization strategies is especially beneficial for pediatric patients and pregnant women as well as individuals requiring repeated follow-up imaging in order to minimize cumulative radiation exposure whilst maintaining diagnostic confidence.[21] Emerging tools such as dosage tracking software, automated exposure analytics, and even artificial intelligence-assisted optimization of protocols are expected to advance radiation safety practices. Such technologies offer immediate feedback on radiation exposure, detection of deviations from protocols, and decision support for healthcare professionals to select imaging parameters tailored to a patient's specific characteristics. With the shift towards value-based imaging under way in healthcare systems, ALARA keeps evolving from a basic radiation reduction concept, into an integrated patient-centered approach that combines technological innovation, quality assurance and evidence-based clinical decision making.[22]

In summary, the ALARA principle is critically important in current-day diagnostic radiology. Successful implementation depends not just on advanced imaging modalities, but also standardized protocols, continuous quality improvement measures, multidisciplinary involvement and lifelong professional education. ALARA enables healthcare providers to offer high-quality imaging services while ensuring patients and providers are shielded from unnecessary radiation exposure by striking a balance between diagnostic effectiveness and radiation safety.[23]

ALARA Implementation in Conventional Radiography and Computed Tomography

Conventional radiography is still the most widely conducted imaging examination worldwide and makes a large contribution to the overall medical radiation dose received by the population. Although the radiation dose associated with a single radiographic examination is low, the increasing number of procedures performed each year makes collaborations between various stakeholders essential to ensure continual optimization. ALARA offers a simple yet applicable concept of both keeping unnecessary exposure within acceptable limits and receiving information from imaging diagnostics. Appropriate exposure parameters, patient positioning and collimation and frequent quality control checks are required to ensure successful implementation.[24] Optimization of exposure factors based on patient size and clinical indication is one of the best techniques for achieving lower patient dose in conventional radiography. The impact of appropriate adjustment of tube voltage (kVp), tube current-time product (mAs), source-to-image distance and filtration on radiation dose and image quality is very significant. Modern digital detectors have an extended dynamic range that allows the acquisition of diagnostic quality images with less radiation exposure than traditional film-screen systems. Nonetheless, with the development of these technologies came an ancillary occurrence called dose creep, a phenomenon in which it is common practice to increase exposure as digital systems will still produce acceptable images at higher doses. As a result, regular monitoring of exposure indices has become an integral part of quality assurance programs.[25] In addition to proper beam collimation, beam collimation is a basic requirement for implementing ALARA. Limiting the X-ray beam to the anatomical region of interest minimizes unnecessary adjacent tissue irradiation, decreases scattered radiation and therefore has an important impact on image contrast and occupational exposure. Patient positioning and immobilization techniques are also utilized to minimize motion artifacts and limit the need for repeat examinations, a major contributor to unnecessary radiation exposure in many imaging departments.[26] CT poses much bigger radiation protection issue because CT examinations usually administer much higher doses in comparison with routine radiography. The escalating use of multidetector CT scanners has enhanced diagnostic capabilities but has also increased the proportion of dose ascribed to CT in terms of the total collective radiation dose from medical imaging. That is the main reason why optimization strategies are applied in CT imaging setting. As a result, patient-specific protocol selection has emerged as one of the most promising strategies for implementing ALARA in CT practice. Rather than applying protocols to every patient uniformly, modern CT systems allow for adjustments in exposure parameters that vary by the size of the patients, the anatomical region being scanned and the clinical question. In tube current modulation, the radiation output is automatically adjusted over the course of a scan to only provide as much radiation as necessary to generate a good image. This approach has shown substantial dose reductions with maintained diagnostic-confidence.[27] A distinct technological evolution is having the machine automatically select tube voltage. Although lower tube voltages can be used to reduce radiation dose by increasing iodine contrast enhancement at the same time in small patients or contrast-enhanced studies, the appropriate tube voltage should be selected methodically. These patient-specific strategies align with the patient-centered conception of the ALARA principle, which help to optimize the utilization of radiation in clinical practice.[28] Compared with the past decade, image reconstruction techniques have also advanced significantly. More sophisticated reconstruction techniques mitigate image noise and improve spatial resolution, thereby enabling diagnostic images to be acquired at the same exposure settings as standard x-ray imaging or even lower than previously possible. All these advances have created the basis of a widespread clinical implementation of low-dose and ultra-low-dose CT protocols for tasks like lung cancer screening, renal stone analysis, or follow-up studies in patients who require sequential imaging.[29] Diagnostic Reference Levels (DRLs) still represent important optimisation tools in CT departments that you will usually be aware of. This allows to compare institutional dose metrics with national or regional DRLs and helps in identifying protocols having unnecessarily high radiation exposure. Regular review of dose reports along with collaboration between radiologists, radiologic technologists, and medical physicists fosters an environment for continuous improvement in protocol design and patient safety.[30] The training of radiologic technologists is also an essential aspect necessary for applying ALARA appropriately in both radiography and CT; most individual decisions made by technologists regarding the selection of equipment, exposure optimization strategies, and protocol adaptations to account for patient-specific characteristics are made on a case-on-case basis under regular clinical conditions. Professional development activities throughout this process continually reinforce key concepts in radiation safety and advocate for the ongoing use of validated imaging protocols.[31]

Despite the tremendous progress made in technology, successful dose optimization cannot be accomplished merely by expensive equipment. Clinical justification is still the first principle of radiation protection: every examination has to bring a clear diagnostic benefit. By combining recent, evidence-based recommendations on appropriate referrals with best optimization of imaging protocols, healthcare providers can reduce inappropriate examinations and improve patient care efficiency without sacrificing quality. Thus, ALARA should not be seen only as a technical principle but also a total quality management concept that combines optimal clinical judgment with technological innovation and multidisciplinary teamwork to ensure high standards of safety and effectiveness of diagnostic imaging.[32]

Patient- Centered Dose Optimization and ALARA in Special Populations

Patients who are most sensitive to ionizing radiation, e.g., children and pregnant women, should adhere to this principle even more closely. Acute radiation Leng Children have fast growing tissues and they also live longer than adults, hence they are more likely to develop infection or any other toxicity due to the radiation induced effects. Consequently, imaging protocols need to be optimized according to the diagnostic needs but also with caution in order to minimize radiological exposure. These examinations should be clinically justified, and non-ionizing imaging modalities (ultrasonography or magnetic resonance imaging) must be considered whenever appropriate. Radiographic or CT examinations, when performed, should use exposure parameters individually adapted to the patient's age, body size and clinical indication. Dedication to child-specific imaging protocols and initiatives such as the Image Gently campaign have shown that, in many circumstances, diagnostic image quality can be maintained while significant dose reductions occur.[33] Computed tomography (CT) is more difficult to protect against radiation from because it often administers far higher radiation doses than normal radiography. Multidetector CT has improved the diagnostic accuracy of several diseases but increased the accumulated radiation dose from medical imaging. Therefore, optimizing these protocols based on patient characteristics has become a cornerstone of ALARA implementation. Modern CT systems apply automatic exposure modulation and automatic tube voltage selection principles based on patient size, anatomical region and clinical indications. They minimise superfluous radiation while preserving image quality, and in contrast-enhanced studies a lower tube voltage can improve iodine contrast simultaneously.[34] After reconstruction, several breakthroughs in the medical field can contribute to CT dose optimization. Iterative and advanced reconstruction algorithms help to reduce image noise and enhance spatial resolution, allowing high quality diagnostic images to be obtained at lower radiation doses. These advances have made it possible to perform low-dose and ultra-low-dose CT in various settings, such as lung cancer screening, renal stone quantification, and serial follow-up studies. This is possible thanks to reference levels, which are indispensable for optimization; they enable the comparison of the local dose to a national (or regional) level. Continuous monitoring of dose metrics allows to refine protocols in a process of quality assurance, thereby continuously improving patient safety.[35] Radiation protection cannot be limited to only technology, but has to be patient-centered as well. Conventional beam collimation addresses the X-ray field only to a clinically relevant area of concern while minimizing unwanted exposition of surrounding tissue, limiting scattered radiation and increasing contrast within images. Correct patient positioning and proper immobilization reduce motion artifacts and repetitive examinations to avoid unnecessary radiation exposure. Also, accumulated radiation dose monitoring becomes essential for patients who need a series of imaging exams matching the previous exposure and when clinical indications allow choosing non-irradiated alternatives.[36] Moreover, shrewd workforce preparation transforms vital for ALARA system. Radiation biology, equipment performance, dose optimization techniques and person-specific imaging protocols must be understood by radiologic technologists and radiologists and medical physicists. Annual participation in continuing medical education, evidence-based referral guidelines, and input from the multidisciplinary team guarantee that every test is clinically indicated and performed at the lowest statistically possible radiation dose. ALARA will be the cornerstone of safe, effective and high-quality diagnostic imaging for all patient populations when it is incorporated with technological innovation, quality assurance quality improvement (QAQI), educational initiatives, and shared decision-making.[37]

ALARA in Fluoroscopy and Interventional Radiology

Fluoroscopy and Interventional Radiology are irreplaceable imaging modality with real-time visualization capabilities for therapeutic and diagnostic studies using minimally invasive therapeutic tools/application. In contrast to conventional radiography, these techniques typically involve extended fluoroscopic time and multiple image acquisitions leading to greater radiation exposure in both patients and healthcare workers. As a result, strict compliance with the ALARA principle is needed for minimizing radiation exposure to patients while ensuring procedural efficacy.[38] Fluoroscopic radiation exposure can be significantly improved with a combination of technological and operator solutions. Pulsed fluoroscopy reduces radiation output compared with continuous fluoroscopy without compromising image quality. Reducing fluoroscopy time, using last-image hold, appropriate collimation to limit the size of the x-ray beam at its origin [e.g., aperture or pinhole collimated systems], and limiting projection angles have also all been shown to reduce patient/staff radiation exposure. Automatic dose control and monitoring in modern fluoroscopic systems supports continuous optimization by providing real-time feedback of radiation delivery during the intervention.[39] Operators are frequently in doses of scattered radiation exposure during interventional procedures, which is easily one of the points at that time where protection over visits with healthcare personnel have to be extensively considered. The other subtle but insignificant safety practices include keeping a sufficient distance from the X-ray source, using ceiling and table-side protective shields (if necessary), and protective eyewear like lead aprons, thyroid collars, etc., plus registering occupational exposure with personal dosimeters. Regular performance testing of equipment, quality assurance programs and continued education of personnel in radiation protection reinforce his implementation of ALARA principles. Collectively, these practices improve both patient and occupational safety without degrading the diagnostic accuracy or therapeutic success of fluoroscopically-guided interventions.[40]

Pediatric Radiation Protection

Because of the increased biological effects of ionizing radiation in children than adults, pediatric radiation protection is an essential element of the ALARA principle. As the developing organs have rapidly dividing cells, they are more radiosensitive, and with a longer life expectancy affords increased opportunity for late

radiation-induced effects to develop later in life. Based on these reasons all imaging study performed to children should be deliberate to justify the expected diagnostic or clinical advantages significantly outweighs any risk with respect of radiation.[41] When an examination is indispensable, patient-specific imaging protocols should be used to minimize radiation exposure. Exposure parameters [tube voltage, tube current, and scan range] should be adapted to the age, body size, and clinical indication of children without applying standard adult settings. Collimating beams as appropriately as possible, ensuring that patients are properly positioned and well-immobilized ensures good quality images while minimizing unnecessary radiation exposures and repeat examinations. Whenever applicable, non-ionizing imaging modalities (eg, ultrasonography and magnetic resonance imaging) should be used instead of X-ray or computed tomography.[42]
International initiatives to optimise pediatric dose have reinforced the necessity and importance of children's radiation safety through campaigning for standardized protocols and continuous quality improvement. With proper justification, optimized individual-level techniques and continuing professional education of the healthcare provider, high-quality diagnostic images can be achieved at doses that are as low as reasonably achievable.[43]

Occupational Radiation Safety

Occupational radiation safety is an important component of diagnostic and interventional radiology practice, as health-care personnel are frequently exposed to scattered ionizing radiation emitted during imaging procedures. To maintain occupational exposure as low as reasonably achievable, good radiation protection practices need to implemented consistently by physicians (radiologists) and technologists (including radiologic technologists, nurses and medical physicists). Simple principles time, distance and shielding are the best way to lower radiation exposure. Occupational risk is minimised by limiting the time of exposure, keeping as far away from the source of radiation as possible when it can be done and using protective devices.[44] Scattered radiation is further reduced through the use of personal protective equipment, including lead aprons, thyroid collars, lead eyewear and mobile or ceiling-mounted protective barriers. Personal dosimeters, routinely worn in the workplace, allow individuals to monitor their accumulated radiation exposure on a daily basis and help confirm that personnel doses are within established threshold limits. Continuous education, opportunistic quality assurance and compliance to standardized radiation safety protocols improve workplace safety and engender a practice of continuous radiation protection culture for the entire healthcare personnel involved in medical imaging.[45]

Digital Radiography, Artificial Intelligence, and Dose Optimization

The use of digital radiography has significantly enhanced the empowerment of healthcare professionals to effectively improve radiation dose while ensuring maximum diagnostic image quality as compared to conventional film-screen systems. The rise in detective quantum efficiency for the modern digital detectors is at least one factor that allows reasonable-quality images to be obtained using lower doses of radiation than required by earlier generations of imaging systems. Finally, digital image processing improves contrast and spatial resolution so that repeat examinations due to suboptimal image quality are less likely to occur which decreases cumulative patient exposure.[46] With the arrival of artificial intelligence (AI), this potential for dose optimization in diagnostic imaging has been further expanded. AI-based algorithms provide the ability to personalize, choosing patient-specific exposure parameters like body size (adults vs. children), anatomical region, or the indication for care. AI-supported rapid noise image reconstruction achieves high-fidelity images using lower exposure settings while maintaining diagnostic confidence. AI-powered dose management software can also analyze radiation exposure over time, detect deviations from standard imaging protocols and assist in quality assurance through automatic performance assessment.[47]
This optimization of digital radiography and artificial intelligence has promoted a more efficient workflow by reducing operator-dependent variability while also standardizing imaging protocols among different clinical settings. These technologies encourage adherence to the ALARA principle through a convergence of intelligent dose optimization, real-time quality control and evidence-based decision support. With the rapid development of digital healthcare, AI-assisted imaging will predominantly impact patient safety, diagnostic accuracy, and personalized radiation protection strategies in today radiology practice.[48]

Challenges and Future Perspectives

Despite substantial progress in radiation protection, several challenges remain in the consistent implementation of ALARA across healthcare institutions. Variability in imaging protocols, differences in equipment performance, limited access to advanced technologies, and insufficient radiation protection training continue to influence patient and occupational dose.[49]Future developments are expected to focus on artificial intelligence-driven protocol optimization, automated quality assurance systems, personalized radiation dose management, and continuous professional education. Strengthening multidisciplinary collaboration and integrating emerging technologies into routine clinical practice will further improve radiation safety while ensuring high-quality diagnostic imaging.[50]

Conclusion
The principle ALARA still forms the basis of radiation protection in diagnostic radiology by limiting the exposure from a diagnostic image. Appropriate justification of examinations, optimization of imaging protocols, the use and development of novel technologies, quality assurance and continuing education are essential for its successful implementation. With the rapid development of artificial intelligence, dose monitoring, and personalized imaging protocols, ALARA will further optimize patient and occupational safety while still providing high-quality evidence-based diagnostic imaging.

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