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Patient radiation dose reduction in multidetector computed tomography: Technologies, reconstruction algorithms, and optimization strategies

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Abstract

Computed Tomography (CT) has become an essential diagnostic imaging technology in modern healthcare because of its rapid acquisition, excellent spatial resolution, and numerous clinical applications. However, patient exposure to ionizing radiation and the long-term biological dangers associated with it have become major issues due to the growing use of Multidetector Computed Tomography (MDCT). With the goal of achieving the "As Low As Reasonably Achievable" (ALARA) concept while preserving diagnostic image quality, radiation dose optimization has thus emerged as a top priority in radiology practice [1].

The recent developments in patient radiation dose reduction methods in MDCT are examined in this review paper, with an emphasis on technological breakthroughs, reconstruction algorithms, and optimization techniques. The study examines how dose management is affected by scanner design enhancements such automatic exposure control (AEC), tube current modulation, spectrum imaging, high-pitch acquisition, and detector efficiency increase. Modern image reconstruction techniques that allow for significant dose reduction without sacrificing image quality are highlighted, such as filtered back projection (FBP), iterative reconstruction (IR), model-based iterative reconstruction (MBIR), and artificial intelligence (AI)-based deep learning reconstruction algorithms [2-3].

Protocol optimization techniques designed for various clinical applications and patient demographics, such as paediatric, cardiac, trauma, and oncologic imaging, are also highlighted in the review. As useful strategies for reducing needless radiation exposure, other factors like patient placement, scan length restriction, shielding procedures, low-kVp imaging, and contrast optimization are covered. Additionally, the function of quality assurance programs, diagnostic reference levels (DRLs), and dose monitoring systems in ensuring patient safety is investigated.

The combination of advanced MDCT technology, innovative reconstruction algorithms, and evidence-based optimization methodologies has significantly improved the overall balance between radiation safety and diagnostic efficacy. More research, education, and the use of standardized dose reduction strategies are essential to enhancing patient safety and advancing safer CT imaging globally [4].

Keywords: Multidetector computed tomography (MDCT), radiation dose reduction, iterative reconstruction, artificial intelligence, dose optimization, computed tomography, image reconstruction algorithms, radiation protection

Introduction

Multidetector Computed Tomography (MDCT) has revolutionized modern diagnostic imaging by providing rapid image acquisition, high spatial resolution, multiplanar reconstruction, and improved diagnostic accuracy across various clinical applications. In emergency medicine, cancer, cardiovascular imaging, trauma assessment, neurological evaluation, and regular diagnostic procedures, it has emerged as a crucial imaging modality. Diagnostic efficiency and patient throughput have been greatly improved by MDCT systems' capacity to obtain thin-section volumetric images in a brief scanning period [5].

Concerns about patient exposure to ionizing radiation have been raised by the growing use of MDCT, despite its exceptional clinical benefits. CT scans account for a large amount of medical radiation exposure globally and generates significantly greater radiation doses than traditional radiography. The cumulative risk of radiation-induced biological consequences, including carcinogenesis, may rise with repeated CT imaging, particularly in paediatric patients and those undertaking long-term follow-up. As a result, optimizing radiation dose has emerged as a key concern in modern radiological practice [6].

The cornerstone of radiation safety in CT imaging is still the "As Low As Reasonably Achievable" (ALARA) approach. Dose reduction measures have benefited greatly from recent developments in MDCT technology. Improved radiation management while maintaining image quality has been made possible by methods including spectral CT, tube current modulation, low tube voltage imaging, automatic exposure control (AEC), and increased detector efficiency. Furthermore, sophisticated image reconstruction methods like as model-based iterative reconstruction (MBIR), iterative reconstruction (IR), and artificial intelligence (AI)-based algorithms have shown significant promise in lowering radiation exposure and image noise [7].

With a focus on enhancing patient safety while preserving diagnostic image quality, this review paper offers an overview of modern technology, reconstruction methods, and optimization techniques for radiation dose reduction in MDCT.

Aims and objective

Aims

This review article's objective is to thoroughly investigate and assess the technologies, image reconstruction algorithms, and optimization techniques used in Multidetector Computed Tomography (MDCT) to lower patient radiation dose while preserving high diagnostic image quality and clinical efficacy. Concerns about patient exposure to ionizing radiation and its possible long-term biological effects have grown in importance as MDCT is used more frequently in modern healthcare. As a result, striking the ideal balance between radiation safety and diagnostic precision has become a crucial goal in radiological practice [8].

Recent developments in CT hardware technologies, such as automated exposure control (AEC), tube current modulation, low tube voltage imaging, spectral CT, high-pitch scanning, and improved detector systems that help in dose reduction are the focus of this article [2]. The article also assesses the contribution of sophisticated image reconstruction techniques to reducing radiation exposure while maintaining image quality, including filtered back projection (FBP), iterative reconstruction (IR), model-based iterative reconstruction (MBIR), and artificial intelligence (AI)-based deep learning reconstruction methods. Additionally, the study aims to evaluate dose monitoring procedures, patient-specific scanning strategies, and protocol optimization techniques that support the application of the ALARA principle and advance safer, more efficient CT imaging in clinical settings [4, 7].

Objectives

The present technology, reconstruction methods, and optimization techniques for radiation dose reduction in Multidetector Computed Tomography (MDCT) are assessed in this review paper. The review's goal is to assess how crucial it is to reduce radiation exposure while preserving patient safety and diagnostic image quality. It focuses on technology developments that support dose optimization, including spectral CT, low-kVp imaging, tube current modulation, and automatic exposure control (AEC), high-pitch acquisition, and enhanced detector technologies [2].

The article also aims to evaluate how well image reconstruction methods, such as filtered back projection (FBP), iterative reconstruction (IR), model-based iterative reconstruction (MBIR), and deep learning algorithms based on artificial intelligence (AI), reduce radiation dose without sacrificing diagnostic performance [4,9]. Analyzing protocol optimization techniques and patient-specific strategies based on age, body habit, and clinical indications is another goal of the review. Dose reduction techniques in paediatric, cardiac, trauma, oncologic, and lung screening CT exams are given particular consideration. The article also looks at how dose monitoring systems, quality assurance initiatives, and Diagnostic Reference Levels (DRLs) support safe CT procedures [10-11]. Finally, it seeks to recognize new trends and offer evidence-based suggestions for efficient radiation dose control in standard MDCT imaging.

Methodology

This narrative review was conducted to evaluate current technologies, image reconstruction algorithms, and optimization strategies for radiation dose reduction in Multidetector Computed Tomography (MDCT). Relevant literature was identified through a comprehensive search of electronic databases, including PubMed, Scopus, Web of Science, and Google Scholar. Keywords used in the search strategy included “MDCT dose reduction,” “computed tomography radiation dose,” “automatic exposure control,” “iterative reconstruction,” “model-based iterative reconstruction,” “deep learning reconstruction,” “low-kVp CT,” “diagnostic reference levels,” and “CT dose optimization.”

Peer-reviewed articles, systematic reviews, meta-analyses, clinical studies, and guideline documents published in english were considered. Particular emphasis was placed on studies evaluating technological innovations, reconstruction algorithms, protocol optimization techniques, and patient-specific dose management approaches. The collected literature was critically reviewed and synthesized to provide an evidence-based overview of current practices and future directions in CT radiation dose optimization.

Technologies for radiation dose reduction in mdct

Recent advances in MDCT technology have significantly contributed to reducing patient radiation exposure while maintaining diagnostic image quality. One of the most effective developments is Automatic Exposure Control (AEC), which automatically adjusts tube current according to patient size, anatomy, and attenuation characteristics. AEC systems optimize radiation output during scanning and have demonstrated dose reductions ranging from 20% to 40% without compromising image quality [2, 12].

Tube Current Modulation (TCM) further enhances dose optimization by dynamically adjusting the tube current during image acquisition. Angular and longitudinal modulation techniques reduce unnecessary radiation exposure by tailoring the radiation output to the patient's anatomy. Studies have reported substantial reductions in patient dose through the implementation of TCM protocols [13].

Low tube voltage (kVp) imaging has emerged as another important strategy for dose reduction. Lowering tube voltage increases iodine contrast enhancement while reducing radiation dose. This approach is particularly valuable in paediatric imaging, vascular studies, and contrast-enhanced examinations. However, low-kVp imaging must be balanced against increased image noise, which can be mitigated through advanced reconstruction techniques [14-16].

High-pitch acquisition techniques available in modern dual-source CT scanners enable rapid image acquisition, thereby reducing scan time and radiation exposure. High-pitch protocols have shown particular value in cardiac CT imaging, where motion artefacts can be minimized while simultaneously lowering patient dose [17-19].

Advances in detector technology have also improved dose efficiency. Modern detectors exhibit higher quantum efficiency and better signal capture, allowing acceptable image quality at lower radiation exposures. Spectral CT and photon-counting detector technologies represent emerging innovations with significant potential for further dose optimization [20-22].

Image reconstruction algorithms

Image reconstruction algorithms play a critical role in balancing image quality and radiation dose. Traditional Filtered Back Projection (FBP) has been widely used because of its computational efficiency. However, FBP is associated with increased image noise at lower radiation doses, limiting its utility in dose reduction strategies.

Iterative Reconstruction (IR) techniques were developed to overcome these limitations. IR algorithms reduce image noise and improve image quality by repeatedly comparing acquired data with estimated image models. Clinical studies have demonstrated dose reductions of approximately 30–50% while maintaining diagnostic confidence [23]. [Table 2]

Model-Based Iterative Reconstruction (MBIR) represents a more advanced form of iterative reconstruction. MBIR incorporates detailed models of scanner physics, detector characteristics, and image statistics, resulting in superior noise suppression and spatial resolution. Dose reductions exceeding 60% have been reported in selected applications, although increased computational requirements remain a limitation [4, 24].

Artificial Intelligence (AI)-based and Deep Learning Reconstruction (DLR) algorithms represent the latest generation of reconstruction technology. These approaches utilize neural networks trained on high-quality image datasets to suppress noise and improve image quality. Recent evidence suggests that DLR can achieve image quality comparable to standard-dose CT while permitting substantial reductions in radiation exposure. The integration of AI-based reconstruction into routine clinical practice is expected to play a major role in future CT dose optimization [25-26].

Protocol optimization strategies

Protocol optimization is essential for minimizing radiation exposure while preserving diagnostic efficacy. Tailoring scan parameters to patient size, clinical indication, and anatomical region is a fundamental principle of CT dose management [1,8].

In paediatric imaging, dose reduction is particularly important because children exhibit greater radio sensitivity and longer life expectancy. Paediatric protocols should incorporate low-kVp settings, reduced tube current, and strict scan length limitation. The Image Gently campaign has significantly contributed to awareness and implementation of paediatric dose optimization practices [11, 27]. [Table 1]

Cardiac CT examinations benefit from prospective ECG-triggered acquisition, high-pitch scanning, and iterative reconstruction techniques. These approaches have reduced effective radiation doses from historically high levels to below 1–5 mSv in many clinical scenarios [28-29].

In oncologic imaging, repeated follow-up examinations contribute to cumulative radiation exposure. Protocol optimization through low-dose techniques, adaptive scanning parameters, and advanced reconstruction algorithms can substantially reduce cumulative patient dose without affecting lesion detection [30].

Trauma imaging protocols require careful balancing of diagnostic urgency and radiation safety. Selective scanning approaches, optimized acquisition parameters, and avoidance of unnecessary multiphase examinations contribute to effective dose management [23].

Dose monitoring, quality assurance and diagnostic reference levels

Dose monitoring systems have become essential tools for radiation safety management in CT practice. Modern dose-tracking software allows continuous surveillance of $CTDI_{vol}$, Dose Length Product (DLP), and effective dose estimates, facilitating identification of unusually high-dose examinations [30].

Diagnostic Reference Levels (DRLs) provide benchmark values for common CT examinations and serve as important quality assurance indicators. Facilities that consistently exceed DRL values should review and optimize their imaging protocols [31].

Quality assurance programs involve routine equipment performance testing, protocol audits, staff education, and continuous monitoring of radiation exposure metrics. These programs ensure compliance with radiation protection principles and contribute to ongoing improvements in patient safety [32].

Future perspectives

Emerging technologies such as photon-counting CT, AI-driven protocol selection, automated dose monitoring platforms, and personalized imaging protocols are expected to further enhance dose optimization. Integration of machine learning algorithms into CT workflow may enable real-time adjustment of acquisition parameters according to individual patient characteristics, improving both radiation safety and diagnostic performance.

Conclusion

Radiation dose optimization remains a critical component of modern MDCT practice. Technological advancements including automatic exposure control, tube current modulation, low-kVp imaging, high-pitch acquisition, and improved detector systems have significantly reduced radiation exposure. Advanced reconstruction techniques such as iterative reconstruction, model-based iterative reconstruction, and deep learning reconstruction have further improved image quality while enabling substantial dose reduction. Combined with protocol optimization, dose monitoring systems, quality assurance initiatives, and adherence to Diagnostic Reference Levels, these innovations support the ALARA principle and promote safer CT imaging. Continued research, technological development, and professional education will be essential for achieving further improvements in radiation safety and diagnostic efficacy.

Declarations

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Table 1: Major Radiation Dose Reduction Technologies in MDCT

Technology	Primary Function	Dose Reduction Potential
Automatic Exposure Control	Adjusts tube current automatically	20–40%
Tube Current Modulation	Varies mA according to anatomy	Moderate
Low-kVp Imaging	Reduces tube voltage	Moderate to High
High-Pitch Acquisition	Rapid image acquisition	Moderate
Spectral CT	Improved tissue characterization	Indirect
Detector Efficiency Improvement	Better photon utilization	Moderate
Photon-Counting CT	Improved dose efficiency	High
AI-Based Protocol Optimization	Personalized acquisition parameters	Emerging

Table 2: Comparison of Reconstruction Algorithms

Algorithm	Image Quality	Noise Reduction	Dose Reduction Potential
FBP	Standard	Low	Limited
IR	Good	Moderate	24–50%
MBIR	Excellent	High	Up to 60%+
DLR	Excellent	Very High	Approximately 34–89% reported

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