

Review

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Review

Value of Low-Dose CT and Ultralow-Dose CT Protocols in Clinical Practice: A Narrative Review

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Abstract: Computed tomography (CT) is a widely employed imaging modality with diverse clinical applications in pediatric and adult populations, offering numerous advantages. Despite several alternatives to imaging modalities with ionising radiation, CT scans have demonstrated persistent global popularity, contributing to a substantial amount of effective radiation doses for patients. This exposure results in hazards, including stochastic effects that amplify the radiation-induced cancer risk proportionally to the radiation dose received. CT-related radiation comprises a substantial portion of cumulative effective doses within diagnostic radiology, specifically impacting younger patient cohorts undergoing repeated investigations for chronic diseases over time. Scientific literature over recent decades has explored various methods to mitigate radiation doses during medical imaging. One notable strategy involves implementing low-dose and ultralow-dose CT protocols, maintaining diagnostic efficacy in acute and non-acute medical and surgical conditions. Utilising innovative image reconstruction algorithms, such as iterative reconstruction and emerging deep-learning algorithms based on artificial intelligence, plays a pivotal role in achieving an approximately 80% reduction in patient radiation compared to standard doses. This review article discusses the significance of low-dose protocols across a spectrum of acute and chronic medical conditions affecting different body systems.

Keywords: low-dose CT; ultralow-dose CT; radiation dose reduction; clinical applications

Introduction

Computed tomography (CT) has become a popular imaging modality for examining a wide range of disease processes, offering extensive clinical uses for both children and adults in emergency and routine diagnostic settings. Its widespread accessibility, affordability, speed, and relatively non-invasive nature make it popular over other sophisticated investigations like magnetic resonance imaging (MRI). Over the past few decades, advancements in image quality and the reliability and versatility of CT have led to its increased utilisation in clinical practice. Based on the findings of the United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR), about 500,000 patients receive some form of CT examination daily (1). Despite the development of alternative imaging methods that abstain from ionising radiation, CT scans have displayed persistent growth globally. This leads to a significantly more effective radiation dose for the patient than other ionising radiation modalities. **Table I** shows a comparison of estimated effective doses for commonly performed various types of CT examinations (2).

Table 1. Comparison of estimated effective doses for commonly performed radiological examinations².

Radiologic Examination	Effective Dose (mSv)	Range (mSv)
Chest radiography	0.1	0.05–0.24
Mammography	0.4	0.1–0.7
Head CT	2	0.9–4.0
Neck CT	4	0.7–9.0
Standard chest CT	8	4.0–18.0

Low-dose chest CT	1.5	Variable
Coronary CT angiography	15	7–39
Abdominal CT	10	3.5–25
Pelvic CT	8	3.3–10
Multiphase abdominopelvic CT	31	6–90
Spine CT	8	1.5–10
CT colonography	10	4.0–13.2
Whole-body CT	12	7–13.5

Ionising radiation is associated with risks to humans due to deterministic effects, which result in direct effects of high radiation, whereas stochastic effects occur by chance. In stochastic effects, there is no threshold point of radiation, and the cancer risk increases proportionate to the radiation dose. Exposure to >100 mSv of radiation over a lifetime is linked to a 1 in 200 chance of developing radiation-associated cancer (3). CT-related radiation is responsible for about 42% of the total collective effective dose arising from diagnostic radiology (1). A recent meta-analysis demonstrated a disproportionate increase in cancer risks from CT scans for adults, based on 111.6 million adult subjects from Asia, Europe, and America. It also showed the direct relationship between radiation dosage, body site where CT exposure was applied, and the likelihood of cancer risks (4). Therefore, numerous published scientific papers have discussed methods to reduce the lifetime total effective dose while preserving the diagnostic ability of the examination. One such strategy is to utilise low-dose CT (LD-CT) and ultralow-dose CT (ULD-CT) protocols, maintaining reasonably good diagnostic performances in many acute and non-acute medical and surgical conditions

Low-dose CT and ultralow-dose CT.

The fundamental principles of radiation protection in medical imaging include justification and optimisation. Justification involves ensuring that an examination is medically necessary. At the same time, optimisation emphasises the importance of minimising radiation doses in medical imaging while maintaining diagnostic accuracy, in alignment with the principle of “As Low As Reasonably Achievable” (ALARA). Behavioural and technical factors are important in reducing effective doses for the patient. Behavioural factors involve actions and practices undertaken by healthcare professionals and technologists to reduce radiation doses. Technological factors are actions to reduce the tube current (mA, milliampere) and voltage (kVp, kilovolt peak), tube rotation speed (s, seconds), the extent of coverage, employing automatic tube current modulation, optimising the pitch and slice thickness, iterative reconstructions (IR) and newer artificial intelligence-based deep learning techniques.

The goal of LD-CT is to minimise radiation to the patient while achieving maximum image resolution and diagnostic capabilities. To obtain LD-CT, various kVp and mAs settings have been utilised in multidetector computed tomography (MDCT) across different anatomical regions and protocols. Initially, the LD-CT protocols aimed to reduce kVp and/or mAs and image reconstruction was performed with raw data using conventional filtered back projection techniques. Reducing slice thickness has been demonstrated to enhance the ability to detect small objects, such as small renal/ureteric calculi or lung nodules. However, image resolution is significantly impacted due to an increase in image noise (5). There are no specific cutoff levels for kVp and mAs in applying LD-CT and ULD-CT. Studies have shown that the average effective dose in LD-CT is approximately 2 mSv for chest CT in lung cancer screening and less than 3.5 mSv for CT kidney, ureter, and bladder (CT-KUB) (6,7). If the average CT abdomen and pelvis dose falls within the 10-12 mSv range, LD-CT reduces the overall dose by more than 75%. This reduction in radiation dose is highly significant for the patient.

Moreover, employing advanced techniques like IR algorithms and DLT reduces the radiation dose to as low as 1 mSv, thereby minimising image noise in ULD-CT. This reduction is approximately

equivalent to the radiation dose used in abdominal radiographs (0.7 mSv) (7). The clinical application and value of LD-CT and ULD-CT for diagnosing various medical and surgical issues in many body systems are summarised in the following.

Respiratory system.

Lung cancer is the primary contributor to cancer-related deaths globally (8). Early identification of lung cancers could significantly reduce mortality and morbidity. Therefore, regular screening of high-risk populations with LD-CT has significantly reduced lung cancer mortality (9). The value of LD-CT has been explained in various trials with promising results. The US National Lung Screening Trial (NLST) reported a 20% decrease in lung cancer mortality through LD-CT screening. The more recent Nederlands-Leuvens Longkanker Screenings Onderzoek (NELSON) trial reported a 24% reduction compared to not using LD-CT screening. Similarly, the Multicentric Italian Lung Detection (MILD) trial demonstrated a 39% reduction in cumulative cancer mortality over ten years (9). Artificial intelligence (AI) has been incorporated into LD-CT screening programs to reduce false positive rates and screening costs (10). While undergoing LD-CT screening for lung cancer, multiple additional non-cancer-related incidental pulmonary pathologies, such as pleural effusion, emphysema, reticular opacities, and fibrosis, can be detected (11). In one study, emphysema was detected in 23.8% of subjects who underwent LD-CT for lung cancer screening, and more than 75% of emphysema cases were diagnosed for the first time with LD-CT (12). Kubo et al. demonstrated that LD-CT with 50 mAs does not differ significantly from standard dose CT (150 mAs) when diagnosing lung parenchymal, pleural, and mediastinal abnormalities (13). A recent systematic review revealed that standard-dose CT could be replaced with LD-CT for evaluating COVID-19 pneumonia with acceptable image quality (14).

Cardiovascular system

Cardiovascular diseases (CVDs) are responsible for nearly one-third of all deaths worldwide and significantly contribute to healthcare costs (15). These diseases include coronary artery disease, stroke, heart failure, hypertension, peripheral arterial disease, and other vascular and cardiac diseases. Cancer patients have a ten times greater risk of CVD mortality than the general population (16). Therefore, screening and diagnosing these conditions are important to reduce morbidity and mortality, especially during cancer screening.

Coronary artery calcification (CAC) scoring is a recognised predictor of CVD risk and mortality (17). Recent studies have shown that CAC can reliably be quantified during lung cancer screening using LD-CT (18,19). However, inherited drawbacks of LD-CT, such as signal-to-noise ratio and image artefacts, are significantly eliminated by recent LD-CT coupled with AI-based deep learning methods (19).

Aortic valve calcifications (AVC) significantly predict future CVD-associated deaths. LD-CT is a valuable tool for screening individuals at risk and grading the severity of AVC (20). Furthermore, a recent study has assessed the effects of mitral annular calcification (MAC) and CVD mortality using LD-CT in COVID-19 infection (21).

Pulmonary hypertension (PHT) is associated with increased morbidity and mortality and is often difficult to diagnose early due to non-specific patient symptoms. One way to predict PHT is to measure the diameter of the main pulmonary artery (MPA) and evaluate the MPA: ascending aorta ratio. In this context, LD-CT has been used to evaluate vascular diameter in patients undergoing lung cancer screening (20).

Genitourinary system.

The prevalence of urolithiasis ranges from 1% to 20%, resulting in annual healthcare costs amounting to billions of dollars. Nearly one-third of these patients experience recurrence over 10 years. Standard-dose non-contrast CT imposes an additional radiation burden on the patient during

diagnostic workups and monitoring. Therefore, the value of LD-CT of the kidneys, ureters, and bladder (LDCT-KUB) has been emphasised in numerous studies over the last two decades.

A meta-analysis has shown that LDCT-KUB can detect renal calculi > 3 mm with a sensitivity of 93% and specificity of 97%, using an average radiation dose of 1.4 mSv. This represents an approximately 85% reduction in radiation compared to the standard-dose CT-KUB (22) (**Figure 1 and Figure 2**).

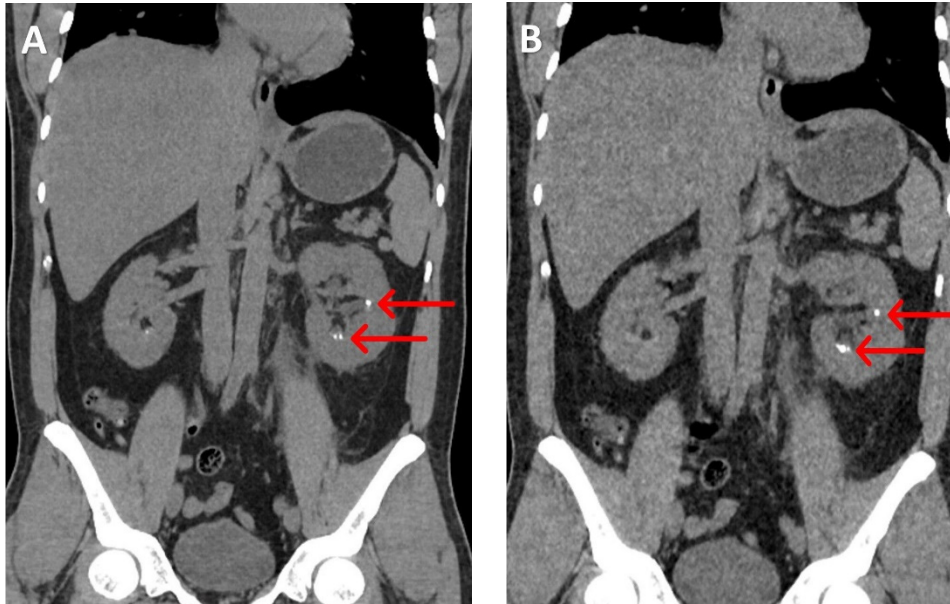


Figure 1. A patient with small non-obstructing calculi (about 3.5 mm) in the left side middle and lower calyces. *A*: Normal dose CT -KUB with effective dose is 20.9 mSv. *B*: The low-dose protocol, with an effective dose of 2.8 mSv, shows the same calculi with good resolution.

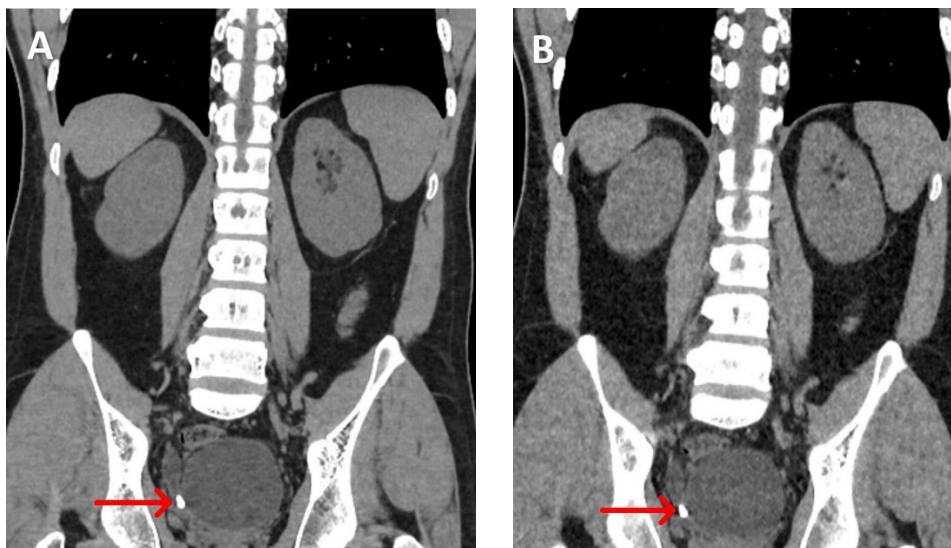


Figure 2. A patient with calculus in right side utero-vesicular junction(9 mm 5.1 mm /density:1050 HU). *A*: Normal dose CT -KUB with effective dose is 19.8 mSv. *B*: The low-dose protocol, with an effective dose of 2.6 mSv, shows the same calculi with good resolution.

Recent studies have further highlighted the potential for reducing radiation doses to sub-millisievert levels using ultralow dose CT techniques.

In a recent publication, Zhang et al. utilised an ultra-low dose CT protocol combined with deep learning reconstruction methods. The study demonstrated a significant reduction in radiation dose (0.64 ± 0.17 mSv) while preserving image resolution and sensitivity for detecting calculi. This

radiation dose is comparable to the 0.7 mSv typically associated with a standard abdominal X-ray and represents a 77% dose reduction compared to LD-CT (23).

Furthermore, whole-body LD-CT could accurately determine the presence or absence of bone metastasis in prostatic carcinoma, guiding clinical decision-making during management (24).

Gastrointestinal system

Acute appendicitis is a leading cause of acute abdomen in childhood and adolescence. Medical imaging plays a vital role in diagnosing appendicitis, both to confirm the diagnosis and to rule out other conditions that mimic appendicitis. Ultrasound is considered the first-line imaging method for diagnosing acute appendicitis in children, with a sensitivity ranging from 71% to 94% and specificity from 81% to 98% (25). However, CT abdomen is primarily used in certain countries and particularly in obese individuals, despite concerns about radiation dose.

As a result, the diagnostic capability of LD-CT has been emphasised in numerous studies. In a meta-analysis by Yun et al., the pooled sensitivity and specificity of low-dose CT were found to be 96.25% and 93.22%, respectively. There was no statistically significant difference between LD-CT and standard-dose CT ($p = 0.71$). This study included a combination of non-contrast and CT studies with IV contrast, and the majority demonstrated radiation doses of less than 2 mSv (26).

Furthermore, during the initial evaluation of the acute abdomen, LD-CT demonstrates a significant diagnostic yield compared to plain radiography and prevents unnecessary additional radiation exposure in standard-dose CT. Acute abdominal conditions benefiting from LD-CT assessment include complete or partial intestinal obstruction, strangulated abdominal wall hernia, internal hernia, colitis, constipation, pancreatitis, acute urinary retention, ascites, hemoperitoneum, and pneumoperitoneum (27).

In assessing hepatic steatosis, LD-CT serves as a more objective evaluation of fatty changes than ultrasonography, which is a more subjective assessment method. Moderate hepatic steatosis, indicated by a pathological liver fat content of 30%, is objectively assessed when the liver attenuation value is < 40 HU in unenhanced LD-CT. Therefore, fatty liver assessment is more readily obtained from LD-CT as an additional finding when performed to achieve another objective, such as renal calculi assessment (28).

Musculoskeletal system.

In acute major trauma, it is essential to rapidly identify life-threatening injuries and those that lead to permanent disabilities. Whole-body CT (WBCT) is considered the standard for managing adult major trauma in many settings, aiding in determining the Injury Severity Score (ISS). The use of WBCT in pediatric trauma patients is debatable due to the associated high radiation doses. Nevertheless, some centres have implemented low-dose WBCT protocols, featuring a mean radiation dosage of 4.8 mSv, in contrast to normal dose protocols with an average radiation dosage of about 20.6 mSv. Therefore, low-dose WBCT significantly reduces the radiation dose by approximately 77% (29).

In acute minor trauma, up to 80% of missed diagnoses in an emergency department are due to missed fractures. Using ultralow dose CT in suspected peripheral skeleton trauma detects more fractures and associated other injuries with relatively similar radiation compared to plain radiography (30).

Further, low-dose lumbar spine CT demonstrates superior image quality with better anatomical and pathological details than X-ray lumbar spine, with a nearly similar radiation dose (31). Low-dose WBCT can be used in multiple myeloma to monitor disease and detect incidental findings, ultimately improving overall management (32).

Head and Neck

Sinusitis is a common upper respiratory disease in pediatric subjects. Though CT is the gold standard for sinus imaging in adults, in children, CT sinuses cannot be used freely due to radiation

burden. Therefore, the value of LD-CT sinuses has been studied in many centres, with a significantly low radiation dose, having a mean effective dose of about 0.0531 mSv compared to plain radiography (mean effective dose of about 0.0528 mSv) (33). LD-CT of the head is valuable in diagnosing intracranial haemorrhage, especially during follow-up, with a 45% reduction of effective dose compared to conventional CT (34).

Conclusion.

This narrative review emphasises the clinical applications and diagnostic value of LD-CT and ULD-CT across various body systems. These protocols have facilitated significant reductions of up to 80% in patient radiation exposure compared to standard doses while maintaining maximum image resolution and diagnostic capabilities. Future research studies are necessary to enhance image quality using AI-based technologies while reducing radiation doses.

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