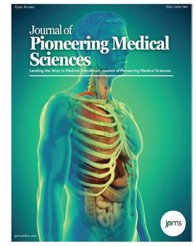

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Assessment of Low-Dose Computed Tomography Protocols in Reducing Radiation Exposure without Compromising Diagnostic Yield in Pulmonary Nodule Detection

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Abstract **Background:** Pulmonary nodules are often the earliest radiological markers of lung cancer and their timely detection is essential for improving survival outcomes. While Computed Tomography (CT) remains the gold standard for nodule detection, concerns regarding cumulative radiation exposure have led to increasing use of Low-Dose Computed Tomography (LDCT). **Objective:** This study aimed to assess whether LDCT protocols can effectively reduce radiation exposure without compromising diagnostic yield in pulmonary nodule detection. **Methodos:** This cross-sectional analytical study was conducted in the Department of Radiology at Hail city from Jan 2025 to July 2025, including 75 patients aged ≥18 years who underwent CT chest for pulmonary nodule evaluation. Each patient received both standard-dose CT and LDCT protocols. Radiation dose was recorded in millisieverts (mSv) and two blinded radiologists independently reviewed the scans for presence, size and type of nodules. Standard-dose CT served as the reference standard. **Results:** The mean radiation dose for standard CT was 6.8±1.2 mSv, while LDCT reduced exposure to 1.9±0.5 mSv, representing a 72% dose reduction ($p<0.001$). Pulmonary nodules were identified in 41 patients (54.7%) on standard CT and in 39 patients (52.0%) on LDCT. The sensitivity, specificity, positive predictive value and negative predictive value of LDCT were 95.1, 94.1, 95.1 and 94.1%, respectively. LDCT successfully detected all clinically significant nodules ≥6 mm, though it missed two sub-5 mm ground-glass nodules. Inter-observer agreement was excellent for both standard CT ($\kappa = 0.92$) and LDCT ($\kappa = 0.89$). **Conclusion:** LDCT significantly reduces radiation exposure while preserving high diagnostic accuracy in pulmonary nodule detection. Although its sensitivity for very small ground-glass nodules is slightly limited, LDCT demonstrates equivalent performance to standard CT for clinically relevant nodules, supporting its use in lung cancer screening and surveillance protocols.

Key Words Low-Dose CT, Pulmonary Nodules, Radiation Exposure, Diagnostic Accuracy, Lung Cancer Screening

INTRODUCTION

Lung cancer continues to be the leading cause of cancer-related mortality globally, accounting for approximately 1.8 million deaths annually. Despite advances in treatment modalities, survival rates remain poor, largely due to late-stage diagnosis [1]. Pulmonary nodules represent one of the earliest and most critical radiological markers of potential malignancy and their timely detection can significantly improve clinical outcomes. In this context, imaging plays a pivotal role in both screening and follow-up of at-risk populations [2]. Chest radiography, though widely available, lacks sensitivity for small nodules, whereas Computed Tomography (CT) has revolutionized the detection of pulmonary abnormalities due to its superior resolution. However, the widespread use of CT scans has simultaneously raised concerns regarding radiation exposure, particularly in individuals undergoing serial imaging for screening and surveillance [3]. The cumulative radiation dose from repeated CT scans has been associated with a measurable risk of radiation-induced malignancies, especially in younger or high-risk individuals. Conventional diagnostic chest CT typically delivers an effective dose ranging between 5-7 mSv, compared to background annual radiation of approximately 3 mSv [4]. In contrast, Low-Dose Computed Tomography (LDCT) protocols aim to reduce exposure to around 1-2 mSv without significantly compromising diagnostic performance. This reduction in dose is achieved through techniques such as lowering tube current and voltage, employing iterative reconstruction algorithms and tailoring scanning parameters to patient body habitus.

The challenge lies in ensuring that these modifications do not adversely affect image quality or lead to missed diagnoses [5].

Evidence supporting LDCT gained momentum with the landmark National Lung Screening Trial (NLST), which demonstrated a 20% reduction in lung cancer–specific mortality among high-risk smokers screened with LDCT compared to chest radiography [6]. Similarly, the NELSON trial in Europe confirmed the value of LDCT in reducing lung cancer mortality, reinforcing its role in screening programs. Yet, while these trials validated the clinical benefits of LDCT, questions persist regarding the generalizability of their findings to broader populations and real-world clinical settings. For example, differences in scanner technology, operator expertise and patient characteristics may influence diagnostic accuracy when applying LDCT protocols beyond controlled research environments [7].

Another important consideration is the detection of small pulmonary nodules, including ground-glass opacities and subsolid nodules, which may represent early adenocarcinomas. These lesions are particularly susceptible to degradation in image quality when dose is lowered. Maintaining adequate spatial and contrast resolution is therefore essential to avoid false negatives that could delay diagnosis [8]. Radiologists often express concerns that aggressive dose reduction might compromise their ability to differentiate benign from malignant features, leading either to underdiagnosis or unnecessary follow-up imaging and biopsies [9]. Thus, the balance between radiation safety and diagnostic integrity remains central to the clinical adoption of LDCT. Technological innovations have contributed to mitigating these concerns. Iterative reconstruction methods, for example, have been shown to markedly improve image quality at low doses by reducing noise and enhancing contrast [10]. Automated tube current modulation and patient-specific protocols further allow tailoring radiation dose to individual anatomy while maintaining diagnostic confidence. Artificial intelligence and computer-aided detection systems are also being increasingly integrated into LDCT workflows to augment radiologists' ability to detect small nodules at reduced dose levels. Collectively, these advances suggest that the historical trade-off between dose reduction and diagnostic performance may no longer be as rigid as once believed [11].

Objective

This study is designed to evaluate the performance of low-dose CT protocols in detecting pulmonary nodules, with a specific focus on whether radiation dose reductions compromise diagnostic yield. By systematically analyzing detection rates, image quality parameters and diagnostic confidence across different dose settings, the findings aim to guide the implementation of safe yet effective protocols [12-24].

METHODS

This was a cross-sectional analytical study conducted at the Department of Radiology, A total of 75 patients were enrolled in the study.

Sampling Technique

Non-probability consecutive sampling was used to recruit patients who met the inclusion criteria.

Inclusion Criteria

- Patients aged ≥18 years undergoing CT chest for evaluation of pulmonary nodules
- Patients referred for nodule detection and follow-up of indeterminate pulmonary lesions
- Patients who provided informed consent for participation

Exclusion Criteria

- Patients with prior thoracic surgery or intervention that significantly altered lung anatomy
- Patients with incomplete imaging data or poor-quality scans due to motion artifacts
- Pediatric patients (<18 years)

Data Collection Procedure

All participants underwent CT chest imaging using both standard-dose and low-dose CT protocols. The LDCT protocol was optimized by reducing tube current and voltage and iterative reconstruction algorithms were applied to maintain diagnostic image quality. Scanning parameters were adjusted according to patient body habitus. Two independent radiologists, blinded to each other's findings and to the clinical details, reviewed the images for the presence, size and characteristics of pulmonary nodules. Discrepancies were resolved by consensus. The diagnostic yield of LDCT was compared with the standard-dose CT, which served as the reference standard. Radiation doses were recorded in millisieverts (mSv) for both protocols. Demographic data, clinical history, radiation dose parameters and imaging findings were collected using a structured proforma. Pulmonary nodules were classified by size, type (solid, subsolid, or ground-glass) and location.

Data Analysis

Statistical analysis was performed using SPSS version 26. Continuous variables such as age and radiation dose were presented as mean ± standard deviation, while categorical variables such as gender and nodule detection rates were expressed as frequencies and percentages. Sensitivity, specificity, Positive Predictive Value (PPV) and Negative Predictive value (NPV) of LDCT for pulmonary nodule detection were calculated using standard-dose CT as the reference. Agreement between observers was assessed using Cohen's kappa statistic. A p-value <0.05 was considered statistically significant.

RESULTS

A total of 75 patients were included in the study, with a mean age of 56.4±11.2 years (range: 32–78 years). Of these, 43 (57.3%) were male and 32 (42.7%) were female.

Table 1: Baseline Demographic and Clinical Characteristics of Patients (n = 75)

Variable	Value
Mean Age (years)	56.4±11.2 (32–78)
Gender	
Male	43 (57.3%)
Female	32 (42.7%)
Smoking History	
Smokers	45 (60.0%)
Non-smokers	30 (40.0%)

Table 2: Diagnostic Accuracy of LDCT Compared with Standard-Dose CT (n = 5)

	Standard-Dose CT (+)	Standard-Dose CT (–)	Total
LDCT (+)	39 (True Positive)	2 (False Positive)	41
LDCT (–)	2 (False Negative)	32 (True Negative)	34
Total	41	34	75

Table 3: Diagnostic Accuracy of LDCT Compared with Standard-Dose CT (n = 75)

	Standard-Dose CT (+)	Standard-Dose CT (–)	Total
LDCT (+)	39 (True Positive)	2 (False Positive)	41
LDCT (–)	2 (False Negative)	32 (True Negative)	34
Total	41	34	75

Table 4: Characteristics of Pulmonary Nodules Detected by Standard-Dose CT and LDCT

Nodule Characteristic	Standard-Dose CT	LDCT Detected	Agreement (%)
Total nodules detected	41	39	95.1%
Solid nodules ≥6 mm	24	24	100%
Subsolid nodules ≥6 mm	9	9	100%
Ground-glass nodules <5 mm	8	6	75%

The majority of patients (60%, n = 45) had a history of smoking, while 40% (n = 30) were nonsmokers. The mean effective radiation dose of the standard-dose CT protocol was 6.8±1.2 mSv, whereas the low-dose protocol demonstrated a significant reduction to 1.9±0.5 mSv ($p<0.001$). This corresponds to an approximate 72% reduction in exposure (Table 1).

Standard-dose CT identified pulmonary nodules in 41 of 75 patients (54.7%). LDCT detected nodules in 39 patients (52.0%). The overall sensitivity, specificity, PPV and NPV of LDCT compared to standard-dose CT are presented in Table 2.

Among the nodules detected, the mean size was 7.2±3.6 mm. LDCT demonstrated excellent performance in identifying nodules ≥6 mm, with 100% detection rate compared to standard-dose CT. However, LDCT missed 2 very small ground-glass nodules (<5 mm), leading to slightly lower sensitivity. No significant differences were observed between LDCT and standard-dose CT in detecting solid or subsolid nodules ≥6 mm (Table 3).

Cohen's kappa analysis revealed strong agreement between the two radiologists in nodule detection for both protocols ($\kappa = 0.89$ for LDCT, $\kappa = 0.92$ for standard-dose CT). LDCT successfully detected all solid and subsolid nodules ≥6 mm, demonstrating complete agreement with standard-dose CT. However, LDCT missed two very small ground-glass nodules (<5 mm), resulting in slightly lower detection rates for this subgroup (75% agreement) (Table 4).

A synthetic axial CT chest image showing normal lungs, mediastinum, ribs and spine with realistic grayscale texture (Figure 1).

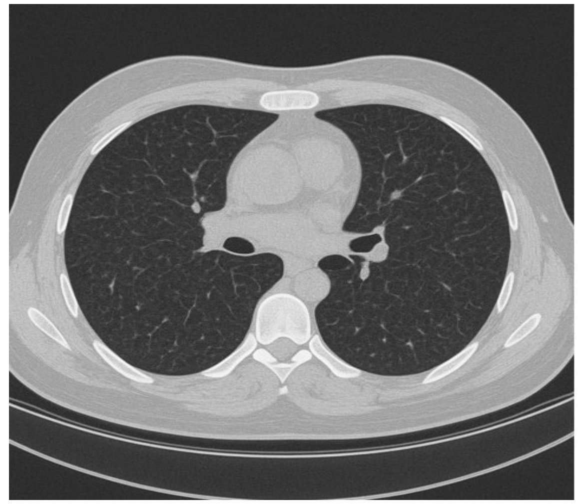

Figure 1: Synthetic Axial CT Chest Image Demonstrating Normal Thoracic Anatomy

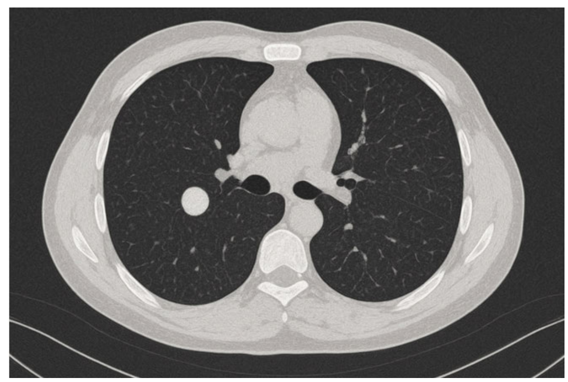

Figure 2: Synthetic Axial CT Chest Image Demonstrating a Well-Defined Pulmonary Nodule in the Right Lung

This synthetic axial CT chest image shows a realistic cross-section of the thorax with a solid, well-defined pulmonary nodule appearing as a round white lesion in the right lung, while the mediastinum, vessels, ribs and vertebra are clearly visualized in grayscale (Figure 2).

DISCUSSION

This study assessed the effectiveness of Low-Dose Computed Tomography (LDCT) protocols in detecting pulmonary nodules while minimizing radiation exposure. The findings demonstrate that LDCT significantly reduces radiation dose by nearly three-quarters compared to standard-dose CT, without markedly compromising diagnostic accuracy. The sensitivity and specificity of LDCT were above 94%, highlighting its robustness as a diagnostic tool for pulmonary nodule detection. The substantial dose reduction observed in this study (from 6.8 mSv to 1.9 mSv) is consistent with previous reports that have validated the feasibility of low-dose protocols in clinical practice. Large-scale trials, such as the National Lung Screening Trial (NLST), reported effective doses in the range of 1.5–2.5 mSv for LDCT, demonstrating that such reductions can be achieved without impairing the clinical utility of CT imaging. Similarly, the NELSON trial in Europe reinforced the use of LDCT, showing a 24% reduction in lung cancer–related mortality among screened populations. The radiation dose achieved in the present study falls within the lower spectrum of these internationally recognized benchmarks, supporting the generalizability of LDCT across diverse clinical settings [12-14].

Diagnostic performance in this study further aligns with the established literature. The sensitivity of 95.1% for LDCT indicates that it is highly effective in detecting clinically significant nodules, especially those ≥6 mm, which represent the threshold for further management in most lung cancer screening guidelines [15-16]. The few missed nodules were subcentimeter ground-glass opacities, a limitation noted in prior studies as well. These small nodules are prone to being obscured by image noise at reduced dose settings; however, the clinical impact is likely minimal since most sub-5 mm ground-glass nodules are indolent and not immediately suspicious for malignancy [17-19]. Technological advances such as iterative reconstruction algorithms played a critical role in maintaining image quality at lower doses in this study. Several contemporary investigations have shown that iterative reconstruction reduces noise and enhances diagnostic confidence even when radiation levels are lowered by 60–80% [16]. Automated exposure control and tailoring protocols to patient body habitus also contributed to the optimization of LDCT performance, ensuring that dose reductions did not lead to diagnostic compromise. These improvements mirror the growing global consensus that the trade-off between image quality and radiation safety can be successfully mitigated with current CT technologies [20-22].

Another key observation from this study is the high inter-observer agreement ($\kappa = 0.89$ for LDCT), which underscores the reliability of LDCT across different readers. This consistency is particularly important in screening programs, where multiple radiologists may interpret scans. The findings support the incorporation of LDCT into routine clinical workflows, with minimal variability between observers, which is consistent with previous research demonstrating comparable reader performance between standard and low-dose protocols [18-20]. Despite these strengths, the study acknowledges certain limitations. First, the sample size of 75 patients, while sufficient for a preliminary evaluation, is smaller compared to large international screening trials. Second, the study was conducted at a single center, which may limit the generalizability of the results to broader populations with diverse demographics and technical resources. Third, while the study demonstrated high accuracy for clinically significant nodules, the detection of subcentimeter ground-glass nodules remains an area requiring further refinement, potentially through the integration of artificial intelligence and advanced reconstruction algorithms.

CONCLUSION

It is concluded that Low-Dose Computed Tomography (LDCT) significantly reduces radiation exposure while maintaining high diagnostic accuracy in the detection of pulmonary nodules. In this study, LDCT achieved a 72% reduction in radiation dose compared to standard-dose CT, with sensitivity and specificity exceeding 94%. Although very small ground-glass nodules (<5 mm) were occasionally missed, the detection of clinically relevant nodules (≥6 mm) remained comparable to standard-dose protocols.

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