

ORIGINAL PAPER

Optimization of Low-Dose CT Protocols for Lung Cancer Screening: A Comprehensive Analysis Using Clinical and Phantom Data

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Abstract. To optimize low-dose computed tomography (LDCT) protocols for lung cancer screening by balancing radiation exposure, image quality, and measurement accuracy. This retrospective study included 190 patients who underwent chest CT using either standard-dose CT (STDCT) or low-dose CT (LDCT). Radiation dose metrics and image quality indicators—such as image noise, signal-to-noise ratio (SNR), and contrast-to-noise ratio (CNR), which reflect how clearly structures can be distinguished—were evaluated. A tissue-equivalent phantom was also used to assess how accurately CT numbers (Hounsfield Units, HU) represent different tissue types under varying scan conditions. Statistical analyses included group comparisons and correlation analysis. LDCT reduced radiation exposure by more than 80%, with a mean effective dose of 1.43 mSv. Although image noise increased, overall image quality remained sufficient for interpretation, particularly in lung tissue. A strong relationship between CT numbers and tissue density was observed in the phantom study, indicating stable measurement accuracy. Optimized protocols achieved radiation doses below 1 mSv while maintaining acceptable image quality. LDCT protocols can substantially reduce radiation exposure without significantly compromising image quality or measurement accuracy. Combining clinical and phantom data provides a practical approach for optimizing CT protocols in lung cancer screening.

Keywords: CT protocol optimization, Low-dose CT, iterative reconstruction, lung cancer screening, Hounsfield Unit accuracy

1. Introduction

Lung cancer is one of the leading causes of death worldwide, and early detection is

essential for improving survival. Computed tomography (CT) is widely used for this purpose because it provides detailed images of the lungs. However, CT imaging involves exposure to ionizing radiation, and repeated examinations may increase long-term health risks (Bushberg et al., 2020).

To reduce this risk, low-dose CT (LDCT) has been developed. Clinical guidelines recommend LDCT for lung cancer screening due to its ability to lower radiation exposure while maintaining sufficient image quality (American College of Radiology, 2014). In general, standard-dose CT (STDCT) delivers higher radiation doses, whereas LDCT and ultra-low-dose CT aim to reduce exposure to safer levels (Fujita et al., 2017; Gobi et al., 2022).

A key challenge in dose reduction is maintaining image quality. Lower radiation levels typically increase image noise, which can make structures harder to distinguish. Modern CT systems address this using iterative reconstruction techniques, which reduce noise and improve image clarity (Geyer et al., 2015).

In addition to visual quality, CT measurements must remain accurate. CT numbers, expressed in Hounsfield Units (HU), are used to differentiate tissue types. However, excessive dose reduction may affect the reliability of these measurements (Vardhanabhuti et al., 2017).

2. Methodology

2.1 Study Population and Ethics

This retrospective study included 190 patients who underwent chest CT between March 2024 and December 2025. Patients were divided into STDCT (n = 95) and LDCT (n = 95) groups. Patients aged 20 years or older with complete imaging and dose data were included. Patients with incomplete data, severe motion artifacts, or unsuitable images for analysis were excluded. The sample size of at least 90 participants to achieve 95% Confidence and 80% Statistical power. Baseline characteristics are shown in Table 1.

The study was approved by the Institutional Review Board of Phayathai Nawamin Hospital (IRB No. 024-2568). Informed consent was waived.

2.2 CT Acquisition Protocol

All scans were performed using a 128-slice CT scanner. STDCT used a higher tube current, while LDCT used a fixed tube current of 30 mA at 120 kV. Other scan parameters

were kept consistent to ensure a fair comparison. Details are provided in Table 2.

2.3 Image Quality Assessment

Image quality was evaluated using regions of interest (ROIs) placed in six areas: tracheal air, lung tissue, fat, muscle, aorta, and pulmonary artery. These regions represent a range of tissue types (Geyer et al., 2015; Tonkopi et al., 2024). The ROI placement and objective image quality measurements were performed by five radiologic technologists to ensure inter-observer consistency (Vardhanabhuti et al., 2017). The observer group consisted of three newly graduated technologists (less than 1 year of experience) and two senior technologists with over 10 years of professional experience in computed tomography. For each region, CT values and image noise were measured. Additional metrics included: SNR (how clearly a structure stands out from noise) and CNR (how well different tissues can be distinguished) (IEC, 2019; McCollough et al., 2011). ROI placement is shown in Figure 1.

Measurements were performed by five observers, and results were averaged.

Table 1. Patient demographics

Variable	STDCT (n = 95)	LDCT (n = 95)	p-value
Sex			0.64
Male	48 (50.5%)	44 (46.3%)	
Female	47 (49.5%)	51 (53.7%)	
Age Distribution (years)			0.93
20–30	9 (9.5%)	7 (7.4%)	
31–40	15 (15.8%)	18 (18.9%)	
41–50	25 (26.3%)	22 (23.2%)	
51–60	25 (26.3%)	30 (31.6%)	
61–70	14 (14.7%)	11 (11.6%)	
71–80	7 (7.4%)	7 (7.4%)	

Table 2. CT parameters

Parameter	STDCT (Standard-Dose)	LDCT (Low-Dose)
Scanner model	Philips Incisive CT (128-slice)	Philips Incisive CT (128-slice)
Tube voltage (kV)	120	120
Tube current (mA)	147.20 ± 37.95	30
Rotation time (s)	0.50	0.50
Pitch	0.80	0.80
Collimation (mm)	64 × 0.625	64 × 0.625
Reconstruction algorithm	iDose ⁴ Level 5	iDose ⁴ Level 5
Patient weight optimization	50–90 kg	50–90 kg

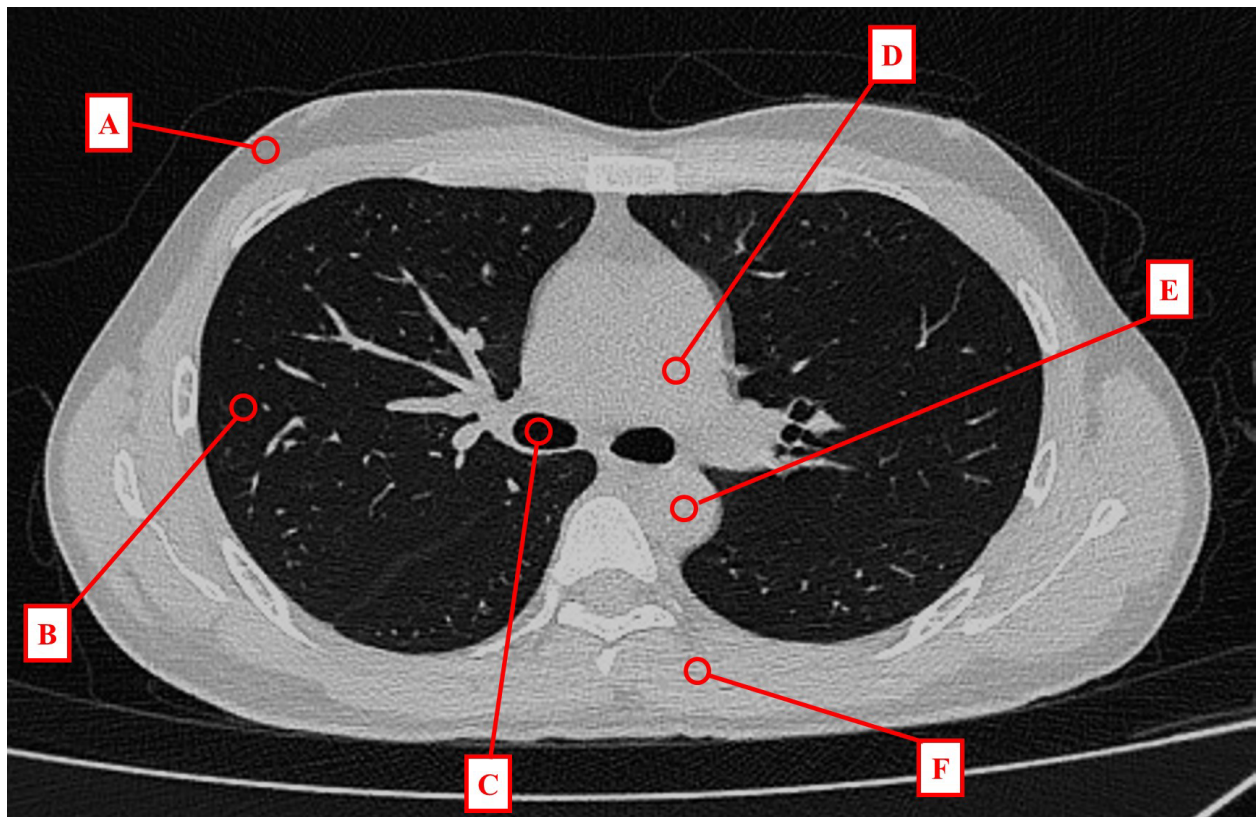


Figure 1. Region-of-interest (ROI) placement in clinical chest CT images at the level of the coronary artery bifurcation. ROIs were positioned in (A) subcutaneous fat, (B) peripheral lung parenchyma, (C) tracheal air, (D) truncus pulmonalis, (E) descending aorta, and (F) paravertebral muscle.

2.4 Radiation Dose Assessment

Radiation dose metrics included CTDI_{vol}, DLP, and SSDE. Effective dose (ED) was calculated using: $ED = DLP \times 0.014 \text{ mSv/mGy}\cdot\text{cm}$. This conversion factor is commonly used for adult chest CT and is based on established dosimetry guidelines (McCollough et al., 2011). Dose comparison is shown in Table 3.

2.5 Phantom Study

A tissue-equivalent phantom was used to evaluate measurement accuracy under controlled conditions. The CTTE phantom (Leeds Test Objects Ltd., Boroughbridge, UK) contained inserts representing different tissue densities. The setup is shown in Figure 2, and protocols are summarized in Table 4.

Table 3. Comparison of radiation dose metrics between STDCT and LDCT

Radiation dose	STDCT	LDCT chest	%difference
	mean $\pm$ SD	mean $\pm$ SD	
CTDIvol (mGy)	11.98 $\pm$ 3.08	2.43 $\pm$ 0.1	-79.72%
DLP (mGy $\cdot$ cm)	541.03 $\pm$ 168.70	102.39 $\pm$ 8.22	-81.07%
SSDE (mGy)	15.52 $\pm$ 3.04	3.43 $\pm$ 0.36	-77.90%
ED (mSv)	7.57 $\pm$ 2.36	1.43 $\pm$ 0.12	-81.11%

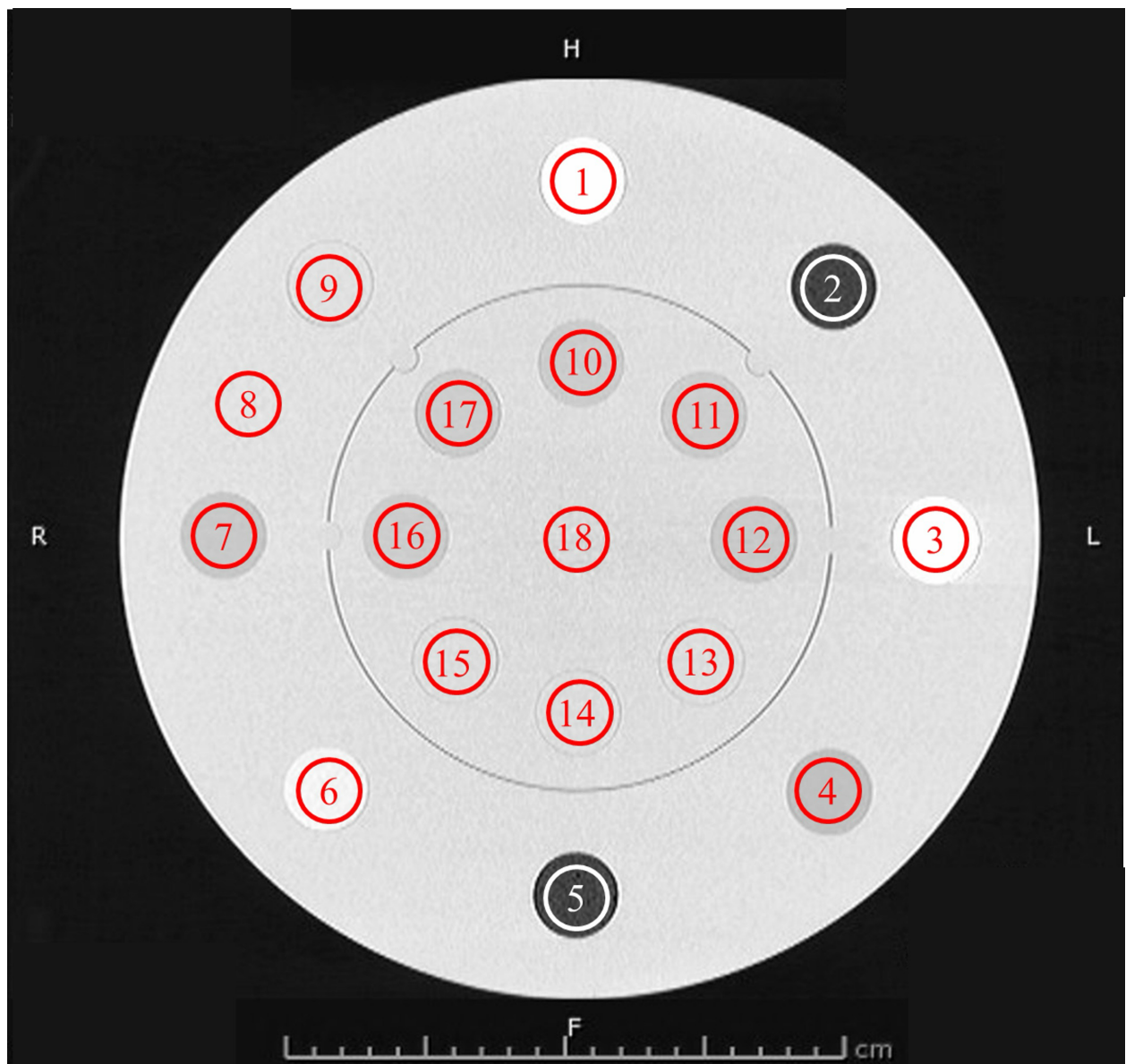


Figure 2. Tissue-equivalent (TE) phantom used for quantitative validation of CT number accuracy. The phantom contains 18 inserts representing different tissue types: (1) RB2 average bone; (2) LN10 lung-300; (3) SB5 hard bone; (4) AP7 adipose; (5) LN10 lung-300; (6) IB7 inner bone; (7) BR12 breast; (8) true water; (9) brain; (10–11, 16–17) WT1 solid water; (12) kidney; (13) liver; (14) soft tissue; and (18) true water.

Table 4. Protocols and estimated dose displayed by the CT scanner software

Protocol	CTDIvol (mGy)	% Diff	DLP (mGy·cm)	% Diff	SSDE (mGy)	% Diff	ED (mSv)	% Diff
LDCT 30mA 120kV (Ref)	2.43	-	95.27	-	4.02	-	1.33	-
LDCT 22mA 120kV	1.77	-27.16%	69.44	-27.11%	2.93	-27.11%	0.97	-27.07%
LDCT 30mA 100kV	1.45	-40.33%	56.85	-40.33%	2.40	-40.30%	0.80	-39.85%
LDCT 11mA 120kV	0.91	-62.55%	35.67	-62.56%	1.59	-60.45%	0.50	-62.41%
LDCT 30mA 80kV	0.70	-71.19%	27.25	-71.40%	1.16	-71.14%	0.38	-71.43%
LDCT 30mA 70kV	0.42	-82.72%	16.45	-82.73%	0.71	-82.34%	0.23	-82.71%

Note: All radiation dose parameters are estimated doses displayed by the CT scanner software prior to the actual scan (Pre-scan dose information)

Nine scanning protocols were tested. CT values and noise were measured for each insert.

2.6 Protocol Optimization

Protocols were evaluated based on three key aspects: image noise, contrast-to-noise ratio (CNR), and the accuracy of CT numbers (Hounsfield Units, HU). To ensure consistent and objective assessment, predefined thresholds were applied. Specifically, CNR was required to remain within $\pm 15\%$ of the reference values, HU deviation was limited to within ± 10 HU, and image noise was allowed to increase by no more than 20%. Protocols that satisfied all these criteria while achieving the lowest possible radiation dose were considered optimized, in line with previous studies on CT dose reduction and image quality optimization (Vardhanabhuti et al., 2017; Tonkopi et al., 2024; Bushberg et al., 2020).

2.7 Statistical Analysis

Data were expressed as mean $\pm$ standard deviation. Independent t-tests and ANOVA were used for comparisons. Pearson correlation was used to assess relationships between CT numbers and electron density. A p-value < 0.05 was considered significant.

3. Results

3.1 Radiation Dose

As shown in Table 3 , LDCT significantly reduced radiation dose across all metrics. The mean effective dose decreased from 7.57 mSv to 1.43 mSv ($p < 0.001$), representing a reduction of more than 80%.

3.2 Image Quality

Results are summarized in Table 5.

3.3 Phantom Validation

The phantom is highly valid for characterizing the relationship between CT numbers and electron density as shown in Figure 3

Moderate to strong correlations were observed between phantom-derived and clinical image quality parameters, with R^2 values ranging from 0.63 to 1.00 depending on the anatomical region and metric evaluated (Table 5).

The correlation analysis was performed by pairing mean SNR and CNR values obtained from clinical images with corresponding measurements derived from phantom scans under equivalent exposure conditions. Although several parameters demonstrated high correlation ($R^2 > 0.90$), some values showed

Table 5. Quantitative image quality parameters.

Parameter	Lung window		
	STDCT chest	LDCT chest	%difference
Image noise (HU)			
Subcutaneous fat	38.87±10.77	41.00±11.70	5.48%
Peripheral lung parenchyma	42.65±9.23	44.02±10.30	3.21%
Air within the trachea	37.02±7.74	39.33±9.35	6.24%
Truncus pulmonalis	50.54±10.23	60.54±15.13	19.79%
Aorta	50.45±9.74	61.57±15.48	22.04%
Paravertebral muscle	52.14±10.35	64.01±15.21	22.77%
CNR			
Peripheral lung parenchyma	18.56±4.34	15.44±4.20	-16.81%
Truncus pulmonalis	0.18±0.14	0.20±0.14	11.11%
Aorta	0.19±0.20	0.18±0.14	-5.26%
SNR			
Peripheral lung parenchyma	21.78±5.39	21.18±4.50	-2.75%
Truncus pulmonalis	0.90±0.23	0.76±0.22	-15.56%
Aorta	0.88±0.23	0.77±0.23	-12.50%

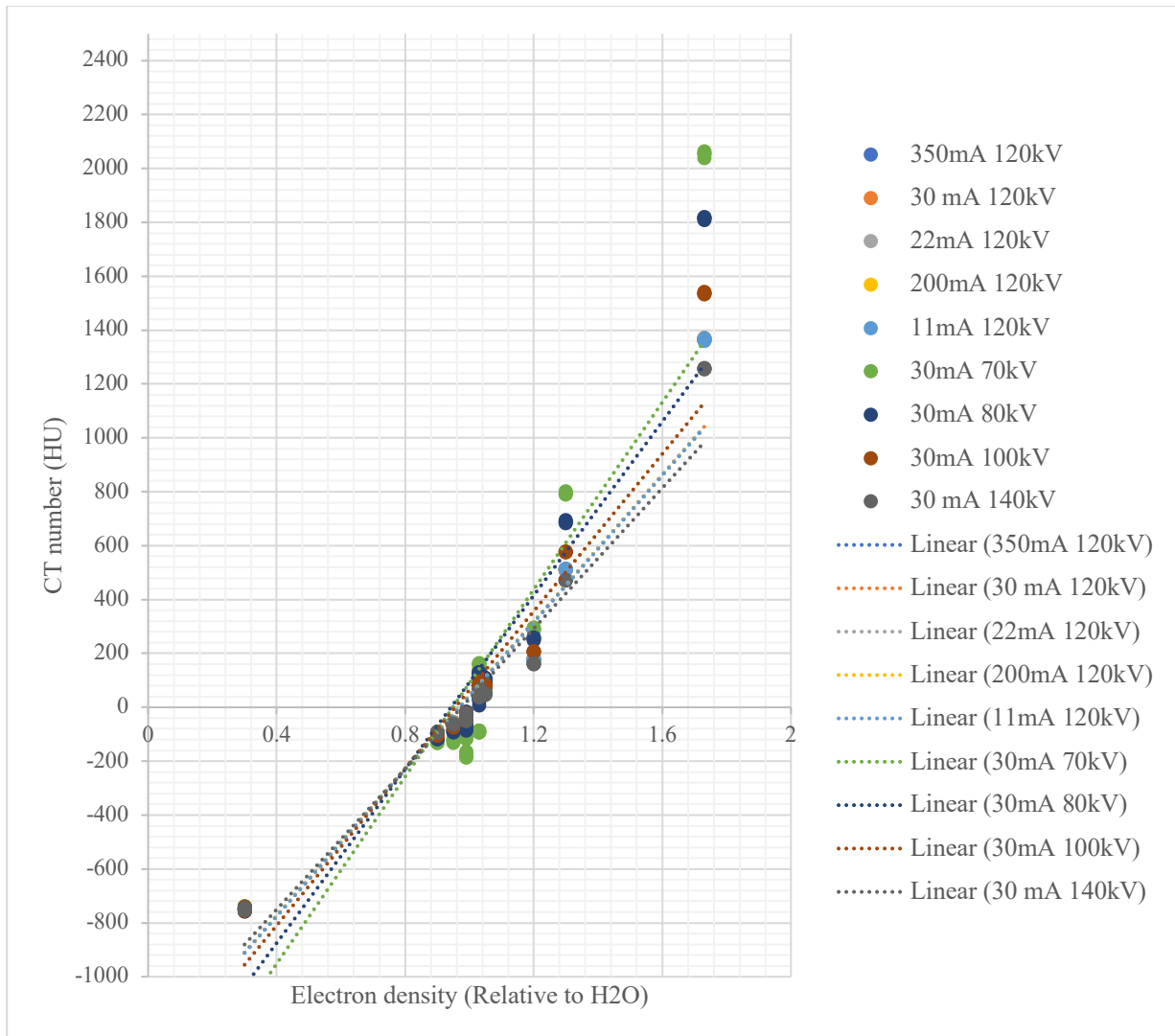


Figure 3. Comparison of CT number accuracy and linearity across multiple kVp and mAs protocols for phantom validation (Lung window)

Table 5. Correlation between STDCT and LDCT (CNR and SNR)

Parameter	Lung window						Soft tissue window					
	CNR			SNR			CNR			SNR		
	L	P	A	L	P	A	L	P	A	L	P	A
<u>STDCT</u>												
Correlation (r)	0.973	0.964	0.966	0.916	0.958	0.794	0.977	0.997	0.980	0.957	0.908	0.959
Coefficient (R ²)	0.946	0.930	0.934	0.840	0.918	0.631	0.954	0.994	0.960	0.916	0.825	0.920
p-value	0.005	0.008	0.034	0.029	0.010	0.109	0.004	0.003	0.128	0.011	0.033	0.010
<u>LDCT</u>												
Correlation (r)	0.956	0.970	0.939	0.929	0.972	0.925	0.951	1.000	0.941	0.962	0.981	0.920
Coefficient (R ²)	0.914	0.940	0.882	0.863	0.946	0.855	0.905	1.000	0.886	0.925	0.963	0.846
p-value	0.011	0.006	0.018	0.022	0.005	0.025	0.013	0.002	0.017	0.009	0.019	0.027

L = Lung parenchyma; P = Truncus pulmonalis; A = Aorta

lower coefficients and non-significant p-values, indicating variability in the relationship between phantom and clinical measurements. Therefore, the results should be interpreted with caution, and overgeneralization of the correlation strength should be avoided.

3.4 Protocol Optimization

Radiation dose decreased progressively across nine protocols. The standard protocol yielded 15.60 mSv, while optimized protocols (22 mA/120 kV and 30 mA/100 kV) achieved 0.97 and 0.80 mSv, respectively (>90% reduction). The lowest dose (30 mA/70 kV). Results are presented in Table 6.

Among the tested protocols, 22 mA/120 kV and 30 mA/100 kV met all predefined criteria. These protocols achieved effective dose levels below 1 mSv while maintaining acceptable image quality. The relationship between CNR number and Dose length product in Figure 4.

4. Discussion

This study shows that radiation dose in chest CT can be substantially reduced while

maintaining acceptable image quality and reliable measurements. The optimized protocols achieved more than 80 % dose reduction, which is consistent with previous multi-center studies on CT dose optimization (Tonkopi et al., 2024).

Although image noise increased, especially in soft tissue, the overall ability to interpret images was preserved. This is likely due to iterative reconstruction, which reduces noise and improves clarity (Geyer et al., 2015).

The findings of this study are also consistent with previous reports showing that LDCT can maintain diagnostic performance, particularly in lung imaging, even at reduced radiation levels (Wassipaul et al., 2023 ; Gobi et al., 2022).

The use of standardized evaluation approaches and quality control methods is important when implementing optimized protocols in clinical practice (International Electrotechnical Commission, 2019; American College of Radiology, 2017).

Table 6. Radiation dose metrics across nine phantom-based protocols.

No.	Protocol	CTDIvol (mGy)	DLP (mGy·cm)	SSDE (mGy)	ED (mSv)
1	STDCT (350 mA, 120 kV)	28.38 ± 0.01	1114.06 ± 0.08	46.89 ± 0.05	15.60 ± 0.01
2	Model (200 mA, 120 kV)	16.22 ± 0.01	636.41 ± 0.38	26.74 ± 0.04	8.91 ± 0.01
3	LDCT (30 mA, 140 kV)	3.59 ± 0.01	140.88 ± 0.01	5.99 ± 0.04	1.97 ± 0.01
4	LDCT (30 mA, 120 kV)	2.43 ± 0.01	95.27 ± 0.01	4.02 ± 0.01	1.33 ± 0.01
5	LDCT (22 mA, 120 kV)	1.77 ± 0.01	69.44 ± 0.01	2.93 ± 0.01	0.97 ± 0.01
6	LDCT (30 mA, 100 kV)	1.45 ± 0.01	56.85 ± 0.01	2.40 ± 0.01	0.80 ± 0.01
7	LDCT (11 mA, 120 kV)	0.91 ± 0.01	35.67 ± 0.01	1.59 ± 0.01	0.50 ± 0.01
8	LDCT (30 mA, 80 kV)	0.70 ± 0.01	27.25 ± 0.01	1.16 ± 0.01	0.38 ± 0.01
9	LDCT (30 mA, 70 kV)	0.42 ± 0.01	16.45 ± 0.01	0.71 ± 0.01	0.23 ± 0.01

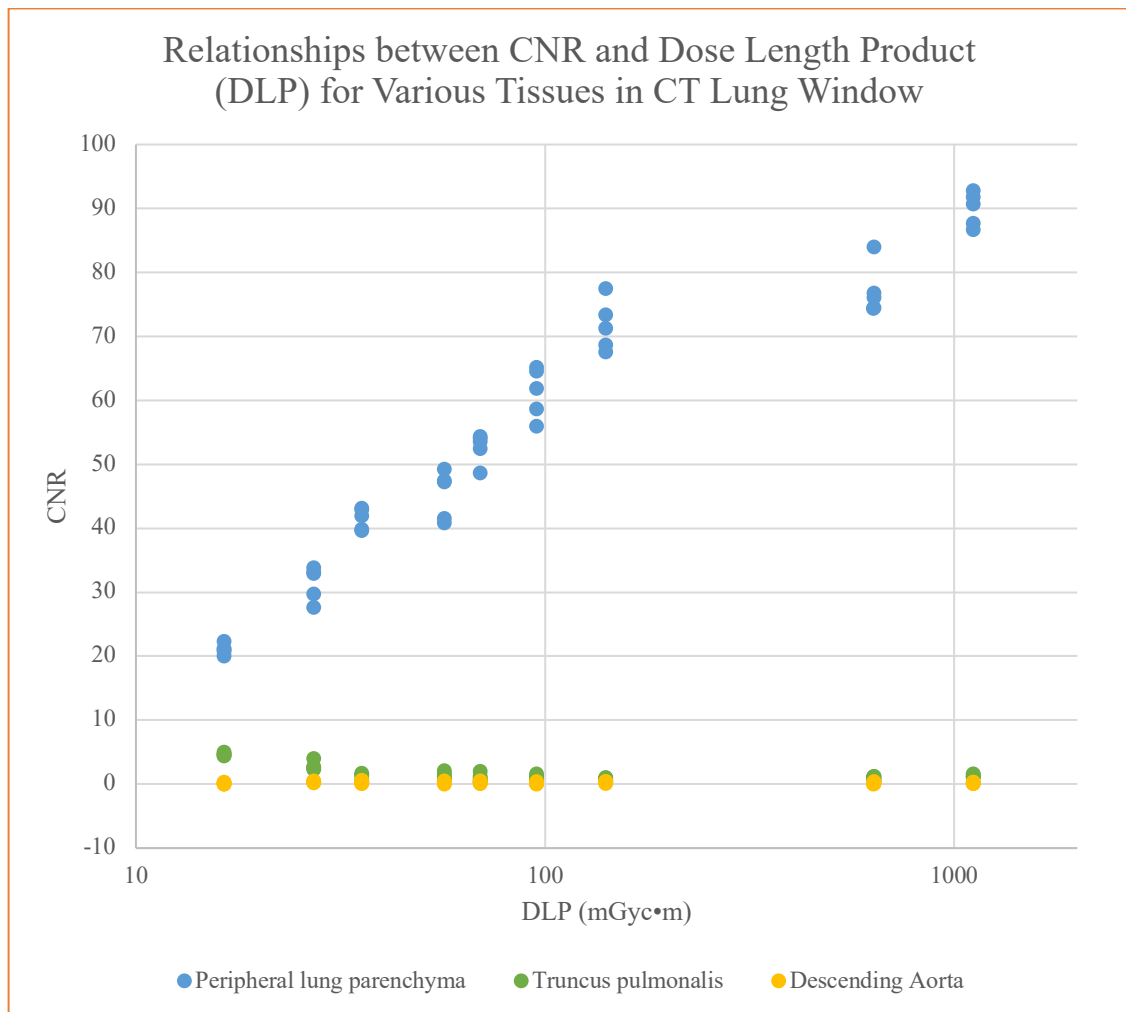


Figure 4. The relationship between CNR number and Dose length product (mGy·cm)

Combining clinical data with phantom validation strengthens the findings. The strong relationship between CT values and tissue density suggests that measurement accuracy is maintained.

However, several limitations should be considered. This was a single-center study using one CT system, which may limit generalizability

Patient-related variability was not fully analyzed, although SSDE partially accounts for this.

Only objective image quality was evaluated. Subjective assessment, such as radiologist interpretation, was not included. The retrospective design may also introduce bias. In addition, phantom studies cannot fully replicate real clinical conditions.

Future studies should include multi-center data and radiologist-based evaluation.

5. Conclusion

Low-dose CT protocols can significantly reduce radiation exposure while maintaining acceptable image quality and measurement accuracy. The combination of clinical and phantom data provides a practical approach for CT protocol optimization.

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