Original Article

Dual-phase computed tomography imaging for lung function assessment in patients with early-stage non-small cell lung cancer

Yizhen Jia[1#], Qinmin Hao[1#], Fen Wang[2], Jun Wang[3], Liang Chen[3], Mei Yuan[1]

[1]Department of Radiology, The First Affiliated Hospital of Nanjing Medical University, Nanjing, China; [2]Department of Radiology, The Affiliated Huai'an No. 1 People's Hospital of Nanjing Medical University, Huai'an, China; [3]Department of Thoracic Surgery, The First Affiliated Hospital of Nanjing Medical University, Nanjing, China

Contributions: (I) Conception and design: M Yuan, Y Jia, Q Hao, L Chen; (II) Administrative support: M Yuan, L Chen; (III) Provision of study materials or patients: L Chen, J Wang; (IV) Collection and assembly of data: Y Jia, Q Hao; (V) Data analysis and interpretation: Y Jia, Q Hao, M Yuan; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

[#]These authors contributed equally to this work.

Correspondence to: Liang Chen, MD. Department of Thoracic Surgery, The First Affiliated Hospital of Nanjing Medical University, 300 Guangzhou Road, Nanjing 210000, China. Email: clbright0909@njmu.edu.cn; Mei Yuan, MD. Department of Radiology, The First Affiliated Hospital of Nanjing Medical University, 300 Guangzhou Road, Nanjing 210000, China. Email: yuanmeijiangsu@163.com.

Background: Early-stage non-small cell lung cancer (NSCLC) requires accurate preoperative lung function assessment, but traditional tests have limitations in evaluating regional lung function. This study aimed to evaluate the efficacy of dual-phase computed tomography (CT) imaging for preoperative lung function assessment in patients with early-stage NSCLC.

Methods: Sixty patients (28 men and 32 women; mean age 55.47±10.30 years) with early-stage NSCLC were prospectively included in this study. The data utilized in this study were retrospectively analyzed from prospectively collected clinical data. Each patient underwent dual-phase (inspiratory and respiratory) CT using dual-energy computed tomography (DECT) before surgery. The DECT parameters, including volume, iodine content, and iodine concentration (iodine content per unit volume) for each lung and lobe in both phases, were collected by a dual-energy workstation and the eXamine software. Semi-automatic lobe segmentation was achieved through the DE Lung Isolation function in the eXamine. Pulmonary function tests (PFTs) before surgery were conducted as the reference standard to assess the accuracy of DECT in lung function evaluation. The correlation between DECT parameters and PFT metrics was analyzed using Spearman correlation.

Results: DECT can achieve stable and reliable semi-automatic lung lobe segmentation. The median iodine concentration in each lobe showed that the left lung had slightly lower values than the right, with the left upper lobe having lower concentrations than the left lower lobe. In the right lung, the middle lobe had the lowest concentration, while the lower lobe had the highest. The Spearman correlation analysis indicated that multiple parameters from DECT correlated with lung function indices measured by PFT ($P<0.05$). Dual-phase functional CT imaging can accurately measure lung function.

Conclusions: Dual-phase CT imaging provides a comprehensive and precise preoperative lung function evaluation of patients who underwent operations for early-stage NSCLC.

Keywords: Dual-phase computed tomography imaging; dual-energy computed tomography (DECT); pulmonary function tests (PFTs); pulmonary nodule; preoperative assessment

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Introduction

Lung cancer remains one of the most significant threats to global health, with an estimated 1.8 million people succumbing to the disease each year (1). Despite progress in immunotherapy and targeted drugs for advanced stages, surgery is still the preferred treatment for early-stage non-small cell lung cancer (NSCLC) (2-4). Preoperative pulmonary function tests (PFTs) are crucial to evaluate pulmonary reserve, operative risks, and predict complications (5-7). Due to the improvement of the detection rate of small nodules, anatomical partial lobectomy (APL) has been gradually promoted in clinical practice, so the requirements for preoperative pulmonary function assessment are also concomitant. Nevertheless, the constraints of PFTs have become increasingly apparent. The PFT-derived lung function indices represent overall lung values but lack the capability to provide specific data regarding a particular lobe's function, which limits their effectiveness in assessing the function as desired by surgeons. Currently, the evaluation of relative pulmonary function is predominantly conducted using single photon emission computed tomography (SPECT) perfusion scintigraphy (8), which continues to be the standard. SPECT also has shortcomings in the quantitative assessment of lobar perfusion, including low spatial resolution, inability to differentiate anatomical lobes, and increased radiation exposure.

Introduced in 2006, dual-energy (DE) imaging technique advances the differentiation of materials through the use of two distinct X-ray energy spectra (9,10). This technology offers a novel imaging method for diagnostic radiology, addressing the limitations of conventional computed tomography (CT) in characterizing tissues and providing functional information (11,12). The technology's advantage lies in its capability to provide simultaneous high-definition anatomical data and detailed pulmonary functional information, thereby facilitating more comprehensive diagnostic and management strategies for patients with lung-related conditions (13).

The use of dual-energy computed tomography (DECT) in assessing pulmonary function has been investigated in various pulmonary diseases, including chronic obstructive lung disease, asthma, and pulmonary embolism (PE). DECT facilitates the measurement of the pulmonary perfused blood volume (PBV), reflecting the distribution of iodine in the lung's parenchyma (11,14). PBV imaging is crucial in diagnosing PE, providing spatial resolution details that computer tomography pulmonary angiography (CTPA) lacks (12). Iodine imaging also holds promise in thoracic oncology by distinguishing benign from malignant pulmonary nodules, characterizing mediastinal lymph nodes, and assessing treatment outcomes (15). Furthermore, DECT-based lung ventilation imaging, employing high atomic number noble gases like xenon (16), predicts residual function post-surgery, detects bronchiolar diseases in asthmatic patients or transplant recipients, and maps ventilation in chronic obstructive pulmonary disease (COPD) (17,18). Due to its multiple advantages in detecting both ventilation and perfusion, DECT has been increasingly utilized in the evaluation of lung lesions.

Research indicates that DECT perfusion imaging surpasses perfusion scintigraphy in accurately forecasting postoperative pulmonary function (19). The authors suggested that this might be due to DECT's precise segmentation and quantification of lobar pulmonary perfusion. The purpose of this study was to evaluate the effectiveness of dual-phase lung functional CT imaging, which relies on dual-phase DECT, for preoperative assessment of pulmonary nodules. The proposed methodology offers an innovative edge over prior

Highlight box

Key findings

- Dual-phase dual-energy computed tomography (DECT) demonstrated precise and reliable semi-automatic segmentation of lung lobes. It was highly correlated with key pulmonary function test (PFT) parameters such as forced expiratory volume in 1 second (FEV1) and diffusing capacity for carbon monoxide (DLCO). This suggests that DECT provides an accurate, lobe-specific assessment of lung function in patients with early-stage non-small cell lung cancer (NSCLC).

What is known and what is new?

- Current methods like PFT and single photon emission computed tomography (SPECT) lack precision and lobe-specific assessment for preoperative lung function evaluation in NSCLC patients as segmentectomy being gradually promoted.
- This manuscript introduces dual-phase DECT as a non-invasive, precise alternative that correlates well with PFT metrics, adding value to surgical planning and enhancing preoperative evaluations.

What is the implication, and what should change now?

- The study suggests that dual-phase DECT should be considered as an alternative or important addition to traditional methods for preoperative lung function assessment. Incorporating DECT in clinical practice could potentially improve the accuracy of surgical decision-making and enhance outcomes for early-stage NSCLC patients.

techniques by utilizing a dual-phase scanning approach during inspiratory and expiratory phases, enabling the acquisition of anatomical and perfusion data for a more precise lung function evaluation. We present this article in accordance with the STROBE reporting checklist (available at https://tlcr.amegroups.com/article/view/10.21037/tlcr-24-871/rc).

Methods

Patients

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by The First Affiliated Hospital of Nanjing Medical University Ethics Review Board (No. 2023-SRFA-337) and the requirement for written informed consent was waived.

We randomly, prospectively selected participants in the Inpatient Department of Thoracic Surgery, The First Affiliated Hospital of Nanjing Medical University. The data used in this study were retrospectively analyzed from the prospectively collected clinical data. Patients suspected of having early-stage NSCLC and undergoing lobectomy or segmentectomy in The First Affiliated Hospital with Nanjing Medical University from March 2022 to January 2024 were finally selected as the study objects. Spirometry and dual-phase DECT were performed as preliminary examinations before surgery, and re-examined at 3 months, 6 months and 1 year after operation. To maximum repeatability and robustness, standardized procedures were followed for DECT scans and PFTs, and all patients were provided with clear instructions to ensure optimal cooperation. Additionally, image artifacts were carefully evaluated, and cases with severe artifacts were excluded.

Inclusion criteria: (I) patients were diagnosed as early-stage NSCLC by postoperative pathology; (II) dual-phase DECT and PFTs performed within one month before surgery; (III) patients underwent anatomic surgery within a single lobe area (for the continuity of postoperative pulmonary function research and to ensure the consistency of the evaluation range, the surgical scope of this experiment was restricted within one single lung lobe).

Exclusion criteria: (I) absence of spirometry data; (II) severe image artifacts or poor coordination; (III) patients who have received surgical resection of lesions in more than two lung lobe regions on the same side; (IV) evidence of lymph node or distant metastasis; (V) history of malignant tumor; (VI) history of preoperative radiotherapy or chemotherapy; (VII) pulmonary vascular disease affecting the scan such as PE.

The baseline evaluation consisted of the collection of information age, gender, operative approach, and pathological examination.

DECT

All patients underwent a CT scan using a dual-source CT scanner (Somatom Force; Siemens Healthcare, Forchheim, Germany). The contrast-enhanced CT was performed with a DE protocol (collimation: 192×0.6 mm; pitch: 0.55; rotation time: 0.25 s). An iodinated contrast agent (Ultravist, 370 mg I/mL) was administered intravenously with a dual-head power injector (Medrad Stellant, Indianola, USA) at a rate of 4 mL/s, with the amount calculated as weight × 1.5 mL, followed by a 30 mL saline flush at the same rate. The peak of the density difference between pulmonary arteries and veins was 2 seconds after the peak of the right ventricular outflow tract, at which time the patient underwent a breath-hold scan at the end of deep inspiration, and deep end-expiratory breath-holding scan was performed with a delay of 30 seconds in the venous phase. The tube voltages were configured at 90 kVp and 150 Sn kVp with a 0.6-mm tin filter. The reference tube current–time products were set to a ratio of 1.3:1 for 90 and 150 kVp (tube A: 80 mAs; tube B: 62 mAs) with automated modulation. Three distinct sets of images were obtained from the DECT scan: 90 kVp, 150 Sn kVp, and a weighted average image, using a ratio of 0.6:0.4 from tube A and tube B. Dose length product (DLP) mean value for single one phase DECT was 240.3 mGy*cm. The radiation dose for dual-phase DECT was about 6.99 mGy, similar to that for contrast-enhanced chest CT.

Semi-automatic lobe segmentation was achieved through the DE Lung Isolation function in the eXamine software (Siemens Healthineers, Erlangen, Germany) (*Figure 1*). The initial automatic segmentation was performed by the DE Lung Isolation function based on anatomical landmarks. When lobar segmentations are incorrectly divided (e.g., due to underdeveloped interlobar fissures), radiologists manually adjusted the results by outlining anatomical landmarks according to the bronchial and pulmonary arteriovenous tracts in the lungs and making corrections across the coronal, sagittal, and axial planes. After these adjustments, the software automatically recalibrated the segmentation.

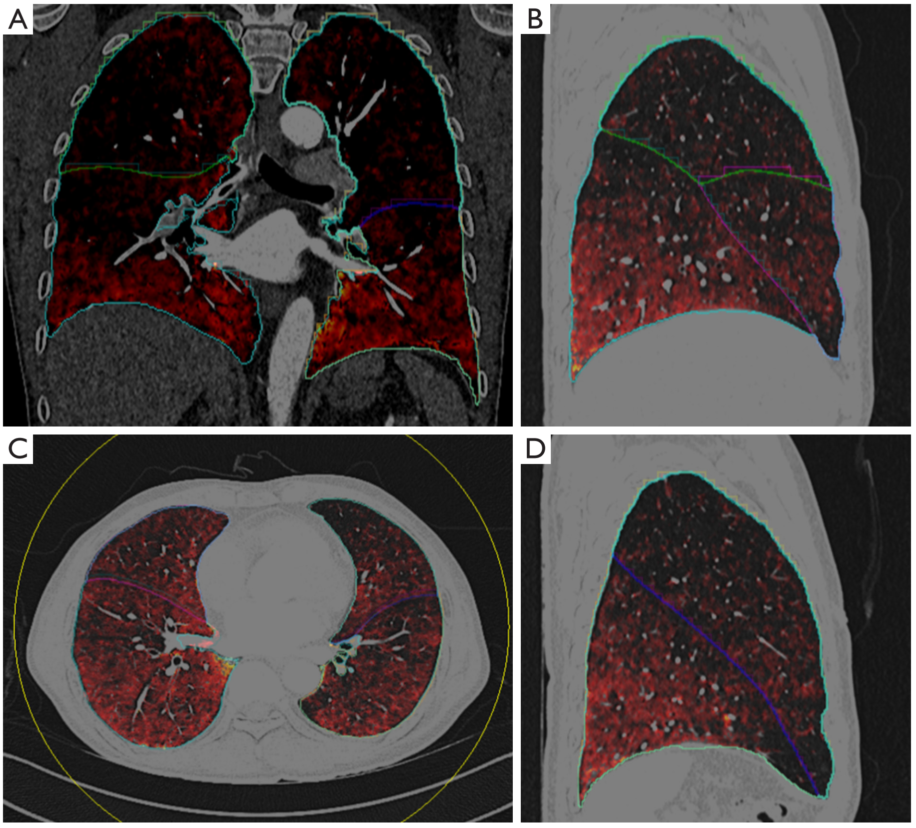

Figure 1 Semi-automatic lung lobe segmentation using dual-energy computed tomography imaging. (A) Coronal view; (B) sagittal view, right lung; (C) axial view; (D) sagittal view, left lung.

Spirometry

All patients used the same respiratory meter (MasterScreen, Erich Jaeger GmbH, Hoechberg, Germany) to measure the pulmonary function before operation at The First Affiliated Hospital of Nanjing Medical University. The pulmonary function indexes were observed and measured, including the measured value of forced expiratory volume in the first second (FEV1), the measured value/predicted value percentage of FEV1 (FEV1%), the measured value of FEV1/the measured value of forced vital capacity (FEV1/FVC%), and the measured value of maximum minute ventilation (MVV), the measured value/predicted value percentage of MVV (MVV%), the carbon monoxide diffusion capacity (DLCO) and the value that has been divided by alveolar volume (VA), DLCO/VA, were also measured.

Statistical analysis

A DE workstation (Syngo.via, version VA30A; Siemens Healthcare) and the eXamine software (version 2.1.55882.0; Siemens Healthcare) were used to measure the volume, iodine content and iodine concentration of the whole lung and each lung lobe. These data were measured by two radiologists using the eXamine software individually, with one physician performing two repeated measurements before and after a two-month interval. Reproducibility was evaluated using intra- and interobserver correlation coefficients. Values for these coefficients ranged from 0.40 to 0.60 for good reproducibility, 0.61 to 0.80 for moderate reproducibility, and 0.81 to 1.00 for excellent reproducibility. And the volume difference, volume ratio, iodine concentration difference and concentration ratio were calculated. After abbreviating deep end-inspiratory

Table 1 Patient characteristics and pulmonary function measurements

Characteristic	Value
Age (years)	55.47±10.30
Sex	
Male	28 [47]
Female	32 [53]
Histology	
Adenocarcinoma in situ	8 [13]
Minimally invasive adenocarcinoma	12 [20]
Invasive adenocarcinoma cancer	33 [55]
Other types	7 [12]
Localization	
Left upper lobe	4 [7]
Left lower lobe	28 [47]
Right upper lobe	3 [5]
Right middle lobe	0
Right lower lobe	25 [42]
Surgical procedures	
Segmentectomy	46 [77]
Lobectomy	14 [23]
Pulmonary function	
Forced expiratory volume in the first second (L)	2.65±0.56
Forced expiratory volume in the first second/ forced vital capacity %	86.30±5.89
Maximum minute ventilation (L/min)	101.68±23.63
Carbon monoxide diffusion capacity (mmol/min/kPa)	7.77±1.61
Carbon monoxide diffusion capacity/alveolar volume (mmol/min/kPa/L)	1.51±0.20

Data are presented as N [%] or mean ± standard deviation.

and deep end-expiratory to DEI and DEE, respectively, volume difference = DEI volume − DEE volume, volume ratio = DEI volume/DEE volume, concentration difference = DEE concentration − DEI concentration, concentration ratio = DEE volume/DEI volume). Spearman coefficient (used for monotonic correlations, applicable to both normal and non-normal data) was used to correlate these results with PFT (the correlation coefficients were calculated separately), with P values of <0.05 considered statistically significant. SPSS 25 (IBM, Armonk, NY, USA) was used for statistical analysis. All continuous variables were tested for normality using the Shapiro-Wilk test. For variables that followed a normal distribution, data were presented as mean ± standard deviation (SD). For variables that did not follow a normal distribution, data were described using median values with interquartile range (IQR).

Results

Patient characteristics from PFT

A total of 105 patients were initially recruited, and after applying the inclusion and exclusion criteria, the final cohort comprised 60 patients. The patient selection process is as follows: 12 patients were excluded due to absence of spirometry data; 6 patients were excluded due to severe image artifacts or poor cooperation during the scan; 3 patients were excluded due to receiving surgical resection of lesions in more than two lung lobe regions; 7 patients were excluded due to evidence of lymph node or distant metastasis; 8 patients were excluded due to a history of malignant tumors; 3 patients were excluded due to a history of preoperative radiotherapy or chemotherapy; 6 patients were excluded due to pulmonary vascular diseases affecting the scan, such as PE. Among these patients, 55% (n=33) were diagnosed as invasive adenocarcinoma cancer (IAC), 20% (n=12) were minimally invasive adenocarcinoma (MIA), and 13% (n=8) were adenocarcinoma in situ (AIS). The remaining 12% (n=7) comprised squamous cell carcinoma (n=5) and large cell carcinoma (n=2). In addition, 46 patients underwent pulmonary segmentectomy and the other 14 patients were performed pulmonary lobectomy. *Table 1* provides a summary of the patient and treatment characteristics.

Continuous variables were first tested for normality using the Shapiro-Wilk test. All pulmonary function parameters (FEV1, FEV1/FVC%, DLCO, DLCO/VA, MVV) were normally distributed, so these data were presented as mean values with SD. For the whole group, the mean value of FEV1, FEV1/FVC%, MVV, and diffusing capacity of the lungs for carbon monoxide, including DLCO and DLCO/VA were 2.65±0.56 L, 86.30%±5.89%, 101.68±23.63 L/min, 7.77±1.61 mmol/min/kPa, 1.51±0.20 mmol/min/kPa/L, respectively.

Lobe segmentation and DECT data

Lobe segmentation using the DE Lung Isolation function in

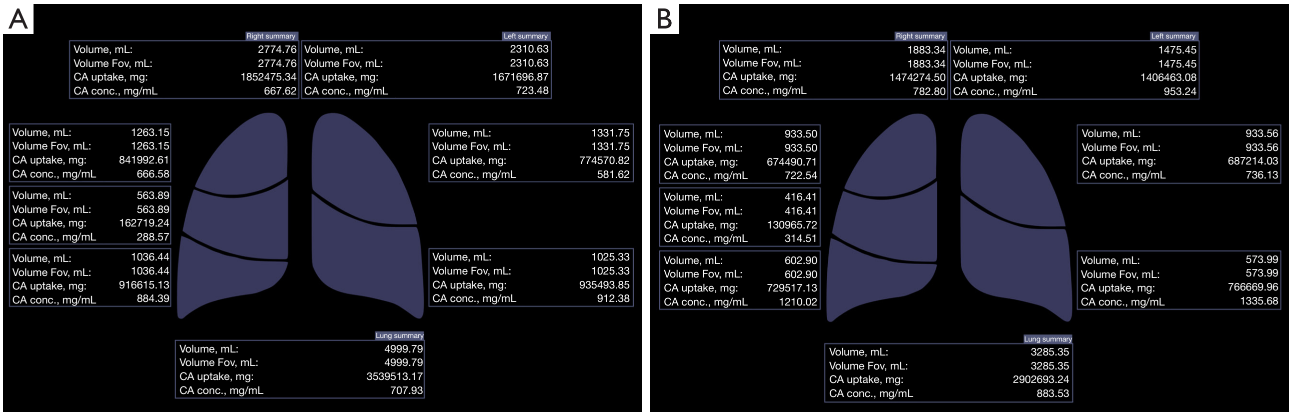

Figure 2 Quantitative perfusion metrics for each lobe and entire lungs, generated using the dual-energy lung isolation function in the eXamine software, are shown for the inspiratory phase (A) and expiratory phase (B).

the eXamine software can achieve stable and reliable results (*Figure 2*). The intra- and interobserver agreements in the measurements of DECT data were excellent (all interclass correlation coefficients >0.800).

The median values with IQR of volume of each lobe were as follows: left upper lobe (LUL) =1,042.57 (919.86–1,315.23) mL, left lower lobe (LLL) =919.71 (744.955–1,119.935) mL, right upper lobe (RUL) =872.34 (761.92–998.65) mL, right middle lobe (RML) =483.26 (345.675–550.175) mL, right lower lobe (RLL) =1,001.6 (818.49–1,211.695) mL. The concentration values were as follows: LUL =282.6 (105.195–518.96) mg/mL, LLL=634.56 (304.56–953.15) mg/mL, RUL = 427.235 (133.505–617.1925) mg/mL, RML =214.62 (125.15–511.55) mg/mL, RLL =691.4 (343–892.805) mg/mL (*Table 2*).

In the left lung, the LUL volume was slightly larger than LLL, while the LLL concentration was higher than LUL. In the right lung, the RML had both the smallest volume and the lowest concentration, and the RLL had both the largest volume and the highest concentration.

The median values with IQR of the DEI volume, DEE volume, DEI iodine content, DEE iodine content and DEI iodine concentration, DEE iodine concentration of the entire lung were 4,066.15 (3,539.64–4,619.18) mL, 2,405.65 (2,151.14–3,203.54) mL, 2,146,047.52 (1,485,480.51–2,913,858.77) mg, 2,315,436.57 (1,889,531.52–2,820,638.86) mg, 455.52 (230.82–708.88) mg/mL, 951.84 (784.61–1,181.46) mg/mL. The median values with IQR of volume difference, volume ratio, iodine concentration difference and concentration ratio were 1,626.04 (1,065.07–2,476.82) mL, 1.70 (1.47–2.06), 506.53 (187.72–699.34) mg/mL and 2.12 (1.25–3.87).

Correlation between DECT data and lung function measured by PFT

The Spearman correlation analysis revealed associations between various DECT parameters and specific lung function metrics measured by PFT (P<0.05). Here is a breakdown of the correlations (*Figure 3*):

(I) Correlations with FEV1
- ❖ Both DEI volume and DEE volume demonstrated positive correlation with FEV1 (r=0.681, P<0.001; r=0.300, P=0.04).
- ❖ The volume difference and volume ratio also showed a positive correlation with FEV1 (r=0.524, P<0.001; r=0.329, P=0.02).
- ❖ Iodine concentration difference and iodine concentration ratio were positively correlated with FEV1 (r=0.413, P=0.003; r=0.446, P=0.001).

(II) Correlations with DLCO
- ❖ DEI volume, DEE volume, and the volume difference were positively linked with DLCO (r=0.502, P<0.001; r=0.303, P=0.04; r=0.347, P=0.01).
- ❖ DEE iodine content was positively correlated with DLCO (r=0.374, P=0.008).

(III) Correlations with DLCO/VA
- ❖ DEI iodine content and DEI iodine concentration showed positive correlation with DLCO/VA (r=0.364, P=0.01; r=0.331, P=0.02).
- ❖ DEE iodine concentration was positively associated with DLCO/VA (r=0.298, P=0.04).

Table 2 Lung lobe volume, iodine content and iodine concentration measurements

Lobe	Volume (mL)	Concentration (mg/mL)
Left upper	1,042.57 (919.86–1,315.23)	282.6 (105.195–518.96)
Left lower	919.71 (744.955–1,119.935)	634.56 (304.56–953.15)
Whole left	2,000.41 (1,640.11–2,335.665)	472.45 (172.1788–701.565)
Right upper	872.34 (761.92–998.65)	427.235 (133.505–617.1925)
Right middle	483.26 (345.675–550.175)	214.62 (125.15–511.55)
Right lower	1,001.6 (818.49–1,211.695)	691.4 (343–892.805)
Whole right	2,176.96 (1,919.395–2,700.385)	519.39 (230.0128–661.44)
Whole lung	4,258.29 (3,539.635–4,824.955)	509.81 (230.82–699.32)

Data are presented as median (interquartile range).

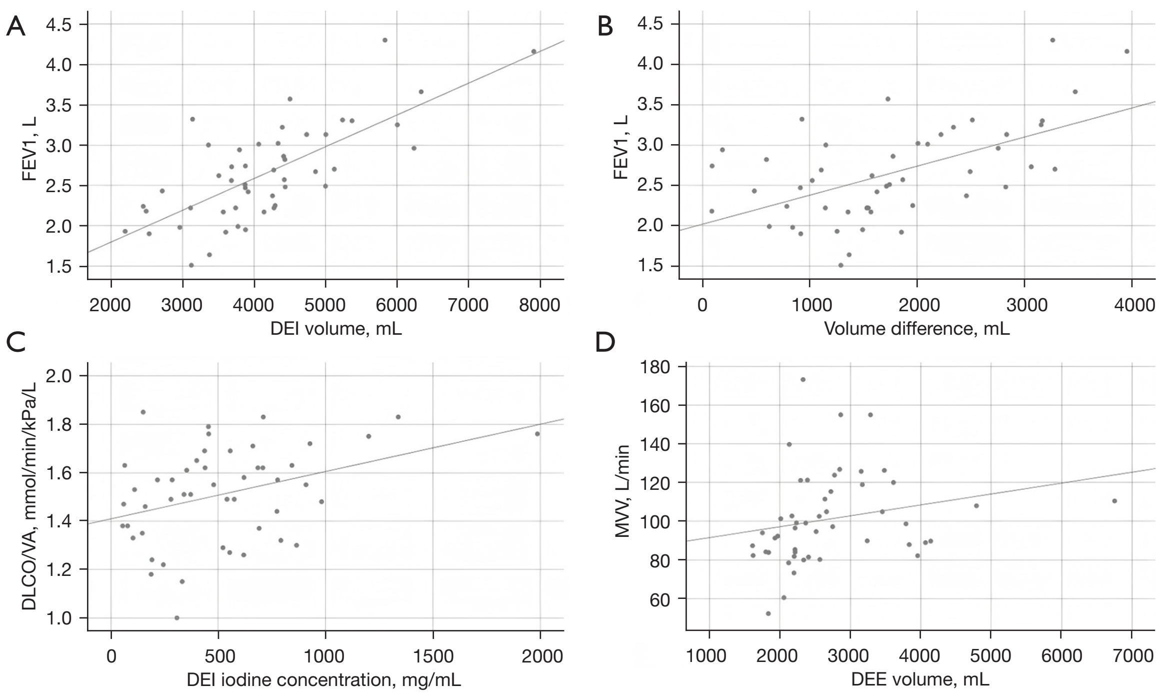

Figure 3 Correlation between dual-energy computed tomography parameters and lung function. (A) FEV1 *vs.* DEI volume (r=0.681); (B) FEV1 *vs.* volume difference (r=0.524); (C) DLCO/VA *vs.* DEI iodine concentration (r=0.331); (D) MVV *vs.* DEE volume (r=0.412). FEV1, forced expiratory volume in the first second; DEI, deep end-inspiratory; DLCO/VA, carbon monoxide diffusion capacity/alveolar volume; MVV, maximum minute ventilation; DEE, deep end-expiratory.

(IV) Correlation with MVV
- ❖ DEE volume was positively correlated with MVV (r=0.412, P=0.003).

Discussion

We have presented an innovative technique utilizing dual-phase CT imaging for the preoperative assessment of lung function for patients with early-stage NSCLC. This method ensures accurate semi-automatic segmentation of lung lobes and shows strong correlations with traditional PFTs. Key findings include significant positive correlations of DECT volumes and iodine concentrations with FEV1 and DLCO/VA, respectively. Further analysis revealed that the iodine concentration was various in each lobe, with the lowest in the right middle lobe and highest in the right lower lobe.

Numerous studies (20,21) have highlighted the close relationship between a patient's pulmonary function and postoperative pulmonary complications, making preoperative assessment crucial. However, advances in surgical techniques for lung cancer have highlighted the shortcomings of traditional PFTs, lacking specific lobar function analysis. SPECT perfusion scintigraphy is a well-studied technique for assessing regional lung function. Nevertheless, pulmonary radionuclide ventilation scanning exposes patients to a significant radiation dose, which is a concern for patient safety.

DECT is a promising technology because it offers the potential to provide high-resolution morphological information along with anatomically matched pulmonary blood volume or ventilation maps in a single CT scan. In addition, the precise depiction of lung lobes and segments, along with their corresponding perfusion information provided by DECT, is instrumental in thoroughly evaluating the impact of different surgical techniques on postoperative pulmonary function.

In order to verify the accuracy of the semi-automatic lobe segmentation method in this study, we collected the volume and iodine concentration of each lobe after segmentation. The volume measurements for the left upper lobe (LUL) were marginally greater than those for the left lower lobe (LLL), while the iodine concentration was higher in the LLL. In the right lung, the right middle lobe (RML) presented with the smallest volume and the lowest iodine concentration, whereas the right lower lobe (RLL) had the largest volume and the highest iodine concentration. These findings align with the outcomes reported in prior research (22,23) using quantitative computed tomography (QCT) and single-photon emission computed tomography (SPECT) methods, confirming the reliability of our segmentation approach.

Prior studies have largely focused on the association between CT parameters and pulmonary function in patients with emphysema or COPD. There are few studies on the relationship between CT parameters and PFT in lung cancer patients. DECT studies have often concentrated on predicting postoperative pulmonary function. For instance, Chae *et al.* (19) highlighted the utility of DECT with PBV maps for predicting postoperative lung function in patients undergoing lung resection, comparing it favorably to perfusion scintigraphy. Additionally, Yanagita *et al.* (24) reported on the use of xenon ventilation DECT for forecasting postoperative pulmonary function. They concluded that analyzing xenon images can predict postoperative PFTs with accuracy comparable to CT volumetry. To the best of our knowledge, this study is the initial one where DECT was employed to assess preoperative lung function in patients undergoing lung resection.

FEV1 is a measure of lung elasticity and airway resistance, while DLCO reflects the lungs' ability to transfer oxygen into capillary blood. Both are dynamic processes and challenging to evaluate solely based on static CT images. However, some dynamic information can be inferred by comparing inspiratory and expiratory scans. This study introduces the innovative use of dual-phase inspiratory and expiratory scanning to capture this dynamic information, enhancing the assessment of pulmonary function.

FEV1, reflecting airflow limitation, represents pulmonary ventilation function, and DEI volume, DEE volume, the volume difference, and the volume ratio are the lung volume indicators. A reduction in ventilation function leads to varying degrees of inspiratory and expiratory dysfunction, with increased expiratory duration and depth and higher exhaled volume, resulting in lower volume indices. Previous studies (25,26) have found that end-inspiratory lung volume measured by CT can evaluate lung volume and ventilation function in patients with lung cancer. The results of our study are consistent with the previous findings, and further found that CT lung volume is not only closely related to ventilation index, but also closely related to DLCO. This suggests that CT-derived lung volume, as a marker of lung ventilation and gas exchange efficiency, serves as a valuable parameter for preoperative evaluation, offering comprehensive insights into pulmonary function.

Maximal voluntary ventilation (MVV) refers to the maximum volume of breath that can be breathed per unit time during pulmonary function measurement. DEE volume was positively correlated with MVV.

The iodine concentration in DECT provides an intuitive, clear indication of lung and lobe perfusion, which is valuable for clinicians in evaluating lung function and planning surgical resection. In DECT, the PBV is considered proportional to the iodine concentration in a specific region at a given time (27). DLCO reaction diffuse lung function is the main index. The effect of VA on diffusion capacity should be excluded. DLCO/VA is commonly used as a correction in clinical practice. DLCO is influenced by factors such as alveolar surface area for gas exchange, the volume of blood in the alveolo-capillary bed, and the volume of alveolar ventilation. Ventilation/perfusion mismatch can lead to regional alveolar hypoxia, which in turn exacerbates local vasoconstriction, affecting DLCO.

This study did not involve explicit groupings based on categorical variables. Therefore, categorical variable analysis was not conducted in this study. However, we acknowledge that in future studies, particularly those focusing on postoperative pulmonary function recovery, the role of categorical variables will be further explored. While this study is limited to preoperative assessment, lung lobe segmentation can be invaluable in the future for evaluating postoperative lung function. By analyzing postoperative CT scans and perfusion maps, clinicians can investigate potential phenomena such as perfusion redistribution and use this information to select the most appropriate surgical approach. Additionally, DECT provides additional insights, such as detailed lung lobe perfusion data, which can complement traditional PFTs, especially in cases where PFTs may not be feasible. The integration of preoperative segmentation data with postoperative follow-up could improve personalized treatment strategies and optimize surgical outcomes. Future research should explore these aspects in more depth, particularly in relation to categorical variables that may influence postoperative recovery.

This investigation into the utilization of dual-phase functional CT imaging for evaluating lung function in individuals with lung nodules indeed faces several limitations.

(I) The study's single-center nature and modest participant count suggest that broader, multi-center research with larger samples is imperative to validate and generalize the findings.
(II) The reliability of PFTs and DECT scans can be influenced by the degree of patient cooperation. Variability in patient compliance during testing can lead to discrepancies between the obtained data and the actual pulmonary function levels.
(III) The radiation dose patients received from dual-phase DECT can be higher than that of single-energy multidetector CT (MDCT) or single-phase DECT.

Conclusions

This study demonstrates that dual-phase CT imaging, using DECT, offers a reliable method for preoperative lung function assessment in patients with early-stage NSCLC. Our findings reveal that DECT can achieve stable and accurate semi-automatic lung lobe segmentation, with multiple DECT parameters correlating significantly with traditional PFTs. These results suggest that dual-phase DECT imaging provides comprehensive anatomical and perfusion data, supporting its use in preoperative planning to enhance surgical decision-making and improve patient outcomes. Future research with larger, multi-center cohorts is needed to validate these findings and confirm the routine clinical applicability of this technique.

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None.

Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by The First Affiliated Hospital of Nanjing Medical University Ethics Review Board (No. 2023-SRFA-337) and the requirement for written informed consent was waived.

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