RESEARCH ARTICLE

Comparative analysis of pulmonary computed tomography imaging and quantitative parameters across diverse stages of chronic obstructive pulmonary disease

Ningyu Tang[1, *], Xuekun Li[2], Fulei Shi[3], Yuxuan Wu[1], Yifan Zhang[1]

[1]Medical Imaging Technology Teaching and Research Office, Zhoukou Vocational and Technical College, Zhoukou, Henan, China. [2]Medical Imaging Department, The First Affiliated Hospital of Xinxiang Medical College, Xinxiang, Henan, China. [3]Imaging Center, Shangqiu Fourth People's Hospital, Shangqiu, Henan, China.

Received: June 9, 2025; **accepted:** November 3, 2025.

Chronic obstructive pulmonary disease (COPD) is a progressive, incapacitating pulmonary condition characterized by persistent airflow limitation and chronic inflammatory responses with smoking being the principal etiological factor. Despite noticeable advancements in both diagnostic modalities and therapeutic interventions, COPD continues to pose a remarkable global health burden with its prevalence and associated morbidity on the rise. This research explored the CT pulmonary imaging features and quantitative parameters linked to varying degrees of COPD severity. A cohort of 120 cases with stable COPD was classified into grade I (mild, n = 24), grade II (moderate, n = 58), grade III (severe, n = 30), and grade IV (very severe, n = 8) groups based on 2011 Global Initiative for Chronic Obstructive Pulmonary Disease (GOLD) strategy. Principal pulmonary function indices including forced expiratory volume in one second (FEV_1), maximum forced vital capacity (FVC), FEV_1/FVC ratio, and FEV_1/predicted value were measured, while routine hematological tests were undertaken. The results demonstrated a significant difference in FVC between cases with grades III and IV COPD in both pre- and post-treatment ($P < 0.05$). Notably, the FEV_1 values in grades II, III, and IV demonstrated significant post-treatment improvement relative to baseline ($P < 0.05$). Importantly, Pearson correlation analysis found a robust positive link of FEV_6 with FVC with correlation coefficients of 0.961 prior to treatment and 0.947 after treatment, both reflecting remarkable changes ($P < 0.05$). The absence of significant alterations in white blood cell count, platelet count, C-reactive protein, or neutrophil percentage was noteworthy across the four groups. Quantitative computed tomography (CT), as a sensitive and reliable tool, was used for the evaluation of emphysema severity in COPD cases, while pulmonary function exhibited noticeable improvement following treatment. The results emphasized the potential of quantitative CT as an outstanding diagnostic instrument for assessing COPD progression, providing further precise insights into the function of CT in evaluating treatment efficacy and guiding personalized therapeutic strategies in clinical practice.

Keywords: chronic obstructive pulmonary disease; alveolar inflammatory factor; computed tomography image; quantitative parameters; lung function.

[*]**Corresponding author:** Ningyu Tang, Medical Imaging Technology Teaching and Research Office, Zhoukou Vocational and Technical College, Zhoukou, Henan 466000, China. Email: 15938675126@163.com.

Introduction

Chronic obstructive pulmonary disease (COPD) is a progressive and debilitating respiratory disorder defined by enduring and gradually worsening airflow limitation, often associated with a range of systemic consequences that extend beyond the pulmonary system [1]. It is caused by chronic inflammation of the airways and lungs in response to toxic gases or particles, leading to the progressive development of airflow limitation. The clinical manifestations of COPD include cough, dyspnea, and an increase in sputum production [2, 3]. This condition leads to a reduction in alveolar elasticity and lung volume, contributing to airway obstruction, acute exacerbations, and other complications that worsen disease severity and prognosis [4, 5]. With over 100 million COPD patients in China alone, the disease has become a major global health problem. In 2020, COPD was the fourth leading cause of death worldwide with nearly 4.5 million deaths attributed to the disease [6].

COPD is influenced by both genetic susceptibility and environmental factors with smoking, dust inhalation, and air pollution being major external contributors. Additional factors such as repeated respiratory infections and poor living conditions also exacerbate the disease [7]. Internal factors include hereditary traits, neonatal infections, and airway hyperresponsiveness. COPD is now the third leading cause of death in developed countries after cerebrovascular disease and ischemic heart disease, significantly affecting individuals' quality of life and work capacity [8, 9]. Current diagnostic methods primarily rely on pulmonary function tests (PFTs) with forced expiratory volume in one second (FEV_1) being a key indicator of disease severity. However, FEV1 alone does not identify the type of ventilatory dysfunction [10, 11]. Despite advancements in COPD understanding, the pathogenesis remains unclear, particularly regarding the early-stage mechanisms induced by smoking and the recurrence of acute exacerbations in some patients even after smoking cessation [13]. Furthermore, the clinical diagnosis of COPD still lacks molecular biomarkers that can comprehensively reflect the disease's severity and prognosis. The current reliance on PFTs alone is insufficient to fully assess COPD, which also involves comorbidities such as cardiovascular diseases, osteoporosis, anxiety, and lung cancer, all of which complicate treatment and management [17, 18]. Hence, there is an urgent need to explore new diagnostic and monitoring methods for better disease management.

This research aimed to figure out the link of computed tomography (CT) imaging characteristics with quantitative parameters in COPD cases across diverse stages of the disease to provide a more detailed understanding of how CT-derived metrics correlated with COPD's severity, promoting more accurate and individualized diagnostic approaches and treatment strategies. The study stratified stable COPD cases into four distinct stages including mild, moderate, severe, and very severe based on the Global Initiative for Chronic Obstructive Pulmonary Disease (GOLD) classification to measure the comprehensive PFTs including the quantification of forced expiratory volume in one second (FEV_1), forced vital capacity (FVC), and their respective ratios, while routine hematological assessments were also implemented. CT imaging was employed to figure out the extent of emphysema and detect other pulmonary pathologies. The link of various CT imaging parameters with pulmonary function (PF) indices was investigated to identify the impact of disease severity on lung architecture and overall function. This study highlighted the potential utility of quantitative CT imaging as a diagnostic modality for assessing emphysema and other COPD-related lung changes. By integrating CT findings with PFT data, the research refined the staging of COPD, enabling more precise treatment stratification. The results remarkably advanced the development of personalized therapeutic interventions, promoting strategies to optimize clinical outcomes and enhance COPD cases' overall quality of life. Additionally, the outcomes provided critical insights into early detection,

monitoring, and progressive assessment of COPD.

Materials and methods

Clinical data and sample collection

A cohort of 120 stable COPD cases, admitted to the First Affiliated Hospital of Xinxiang Medical College (Xinxiang, Henan, China) between January 2021 and January 2024, was recruited in this study, which comprised 70 males aged from 45 to 78 with average age of 62.5 years old and 50 females aged from 47 to 75 with a mean age of 61.2 years old. The patients were grouped into grade I (mild, n = 24), grade II (moderate, n = 58), grade III (severe, n = 30), and grade IV (very severe, n = 8) according to 2011 Global Initiative for Chronic Obstructive Pulmonary Disease (GOLD) guidelines. The COPD diagnostic criteria included comprehensive pulmonary function (PF) assessments; clinical presentation consistent with COPD accompanied by chronic cough, excessive sputum production, and dyspnea; post-bronchodilator FEV_1/FVC ratio less than 70% with confirmation of irreversible airflow limitation; routine chest X-ray examination excluding differential diagnoses involving lung carcinoma, pulmonary fibrosis, bronchial asthma, and other potential causes of dyspnea; stable clinical presentation with no exacerbation of symptoms. The study case inclusion criteria were diagnosis on the basis of the 2007 guidelines from the Chinese Medical Association for COPD; absence of significant clinical exacerbations of expectoration or wheezing defined as a change greater than one diaphragm in the prior month; exclusion with other concurrent respiratory diseases; not undergoing any systemic treatments with the exception of inhaled bronchodilators or glucocorticoids for at least one month prior to blood sample collection. The exclusion criteria included no history of acute respiratory tract infection symptoms in the preceding two months; with established diagnoses of cardiovascular, hepatic, or renal diseases that might confound study outcomes; with psychiatric conditions that could impair cognitive function or interfere with adherence to study protocols; with malignant pulmonary neoplasms, active pulmonary tuberculosis, or severe bronchiectasis with clinically significant respiratory implications. All research procedures were approved by the Ethics Committee of the First Affiliated Hospital of Xinxiang Medical College (Xinxiang, Henan, China) (Approval No. 24-361). All patients received standard treatment according to the 2011 GOLD guidelines for COPD management, which included inhaled bronchodilators (short-acting beta-agonists and long-acting beta-agonists) and inhaled glucocorticoids. Patients were also administered oral antibiotics as needed for exacerbations, and mucolytics were prescribed to assist with sputum clearance. Oxygen therapy was provided for patients with severe hypoxemia, and pulmonary rehabilitation was recommended for eligible patients. The treatment was personalized based on each patient's severity grade as defined by the GOLD classification and adjusted according to the clinical response during follow-up visits.

Pulmonary function tests

PF was measured between 8 am and 12 pm using JAEGER APS-Pro pulmonary function instrument (Jaeger GmbH, Würzburg, Bavaria, Germany). Patients were instructed to sit upright with feet flat on the ground and their head at natural level. After fitting a nose clip, the patient performed a forced exhalation maneuver, breathing in to total lung capacity and exhaling as forcefully and completely as possible. The procedure was repeated after five calm breaths. The various PF parameters including VC, FEV_1/FVC%, and the predicted FEV_1% values were then calculated. PFTs were performed before and after the inhalation of salbutamol sulfate aerosol (Ventoline) (GlaxoSmithKline Pharmaceuticals, Middlesex, UK).

Hematological assessments

Routine hematological assessments including white blood cell (WBC) count, platelet (PLT) count, C-reactive protein (CRP), and neutrophil (NEU) percentage across the four grade groups were implemented through Mindray BC-6800

automated analyzer (Mindray Bio-Medical Electronics, Shenzhen, Guangdong, China).

Quantitative CT examination

The patient underwent CT scanning within a 72-hour window using a GE LightSpeed 64-slice spiral CT scanner (General Electric Company, Fairfield, OH, USA). Subject was positioned in a supine orientation and instructed to inhale deeply to their total lung capacity. Thin-layer spiral CT scanning was undertaken at inspiration's end with the scanning parameters precisely adjusted to ensure high-resolution imaging. Standard reconstruction of images was applied, and the resulting images were transmitted to the AW4.3 processing station for further analysis. The CT Analyzer (Bruker, Billerica, MA, USA) was employed to quantify emphysema by generating a pixel histogram for the designated region of interest. The determination of percentage of lung attenuation area (LAA%) was obtained through Amira software (Thermo Fisher Scientific, Waltham, MA, USA) with an optimal threshold established for the precise analysis of lung tissue damage. Differences in LAA% underwent comparable analysis across the four GOLD classification groups (ABCD stages), and the correlation between LAA% and PF metrics, as well as symptom severity scores, was evaluated to find out the link of structural alterations with clinical outcomes in the cohort. The ABCD groups were defined based on a combination of clinical features, PFTs (e.g., FEV_1/FVC ratios), and CT-derived parameters such as LAA%. Specifically, the groups were categorized as A (mild emphysema with normal PF), B (mild emphysema with obstructive pulmonary dysfunction), C (moderate to severe emphysema), and D (very severe emphysema or advanced COPD with significant functional impairment). The CT images were subsequently analyzed by two experienced radiologists with each having more than five years of specialized practice. The bronchial cross-sectional area and tracheal lumen area for each segment were precisely quantified through an electronic ruler following the image magnification on the display to enhance resolution and precision. To ensure measurements' robustness, each parameter was recorded in triplicate with the average value being calculated for greater accuracy. The ratio of the bronchial area to the total sectional area (Ai/Ao) was derived.

The modified Medical Research Council (MMRC) dyspnea scale questionnaire

The MMRC dyspnea scale is a widely recognized tool developed by the UK Medical Research Council (London, UK), which serves to quantify the severity of dyspnea in COPD cases. The scale stratifies dyspnea into five distinct levels based on degree of breathlessness experienced by the patient during various physical activities. Level 0 corresponds to the presence of dyspnea exclusively during strenuous exertion, while Level 1 is characterized by noticeable breathlessness during moderate physical activities involving walking or ascending a gentle incline. Level 2 denotes a level of breathlessness that impedes the subject's ability to walk at a normal pace on flat ground, requiring them to pause for rest. Level 3 is indicative of breathlessness severe enough to necessitate frequent stops following walking as little as 100 meters or after a few minutes of walking on level terrain. Level 4 represents the most severe form of dyspnea, where the patient is unable to leave the confines of his/her home due to profound breathlessness, or struggles with even basic self-care tasks, comprising dressing or undressing. In conjunction with the MMRC scale, the COPD Assessment Test (CAT) was employed as a more comprehensive tool to figure out the multifaceted health burden imposed by COPD.

COPD PF classification criteria

Based on the 2011 edition of the Global Initiative for GOLD strategy, stable COPD patients were classified into four grades using PF. Grade I (mild) was characterized by an FEV_1/FVC ratio falling below 70%, with an $FEV_1 \geq 80\%$ of the predicted value, which signified a subtle degree of airflow limitation, typically linked with minimal clinical symptoms and a less remarkable impact on daily activities. Grade II (moderate) was defined by an

Table 1. Comparison of general data and pulmonary function among groups.

Index	I (n = 24)	II (n = 58)	III (n = 30)	IV (n = 8)	*P*
Age (years old)	56.26 ± 8.61	57.64 ± 6.36	55.84 ± 6.03	55.84 ± 6.03	0.474
Male	13 (54.17%)	34 (58.62%)	24 (80%)	7 (87.5%)	0.801
Female	11 (45.83%)	24 (41.38%)	6 (20%)	1 (12.5%)	
Smoking index [M (Q_1, Q_3)]	265 (120, 340)	460[a] (317, 647)	420[a] (320, 585)	28.612	<0.001
MMRC score [score, M (Q_1, Q_3)]	2.0 (1.0, 3.0)	2.0 (1.0, 3.0)	1.0 (1.0, 2.0)	1.0 (1.0, 2.0)	<0.001
FEV_1% predicted value	80.69 ± 7.62	45.94 ± 7.62	54.21 ± 6.76	35.12 ± 5.17	<0.001
FEV_1/FVC (%)	83.44 ± 5.96	48.80 ± 15.35	51.56 ± 6.29	46.19 ± 3.18	<0.001

FEV_1/FVC ratio falling below 70% and FEV_1 between 50% and 80% of the predicted value. The airflow obstruction became more apparent, and patients might begin to experience limitations in their physical capacity and exertion tolerance, although they generally remained stable. Grade III (severe) was identified by an FEV_1/FVC ratio falling below 70% and FEV_1 between 30% and 50% of the predicted value, which denoted a significant impairment in PF with patients experiencing remarkable dyspnea, limitations in physical activities, and an increased frequency of exacerbations that negatively influenced quality of life. Grade IV (very severe) demonstrated by an FEV_1/FVC ratio falling below 70% with either FEV_1 less than 30% of the value predicted or FEV_1% predicted falling below 50%, marking the most severe form of COPD with patients exhibiting severe airflow limitation, often accompanying by respiratory failure and systemic manifestations, leading to noticeable disability and a greatly diminished life expectancy without advanced therapeutic intervention.

Statistical analysis

SPSS 21.0 (IBM, Armonk, NY, USA) was employed for statistical analysis. Data that conformed to a normal distribution with equal variances were described as the mean ± standard deviation (x ± s). Chi-square test along with the independent t-test was performed for comparative analysis of categorical data across distinct groups. Variations in the indices were assessed utilizing repeated-measures analysis of variance (ANOVA). P value less than 0.05 was defined as statistical significance. Parameter's between-group consistency was indicated *via* the intraclass correlation coefficient (ICC).

Results

Comparison of general data and PF among groups

The results showed that there was absence of significant difference in age distribution and gender composition among the four groups (Table 1). Significant differences were found in other indices including the smoking index, MMRC score, FEV_1% predicted value, and FEV_1/FVC ratio. The smoking index showed a very significant difference across groups ($P < 0.001$) with higher values in the moderate and severe groups than that in the mild and very severe groups. The MMRC scores were significantly high in the mild and moderate groups ($P < 0.001$). PF parameters such as FEV_1% predicted value and FEV_1/FVC ratio also exhibited very significant differences across the groups with lower values in the more severe disease groups ($P < 0.001$).

Alteration in PF indices pre- and post-treatment

The comparative analysis of PF indicators among the four groups showed that the FVC demonstrated a significant difference between grades III and IV when comparing pre- and post-treatment values ($P < 0.05$) (Figure 1A). FEV_1 showed remarkable differences in grades II, III, and IV between pre- and post-treatment assessments ($P < 0.05$) (Figure 1B). FEV_6 displayed remarkable differences across grades I, II, III, and IV pre- and post-treatment ($P < 0.05$) (Figure 1C).

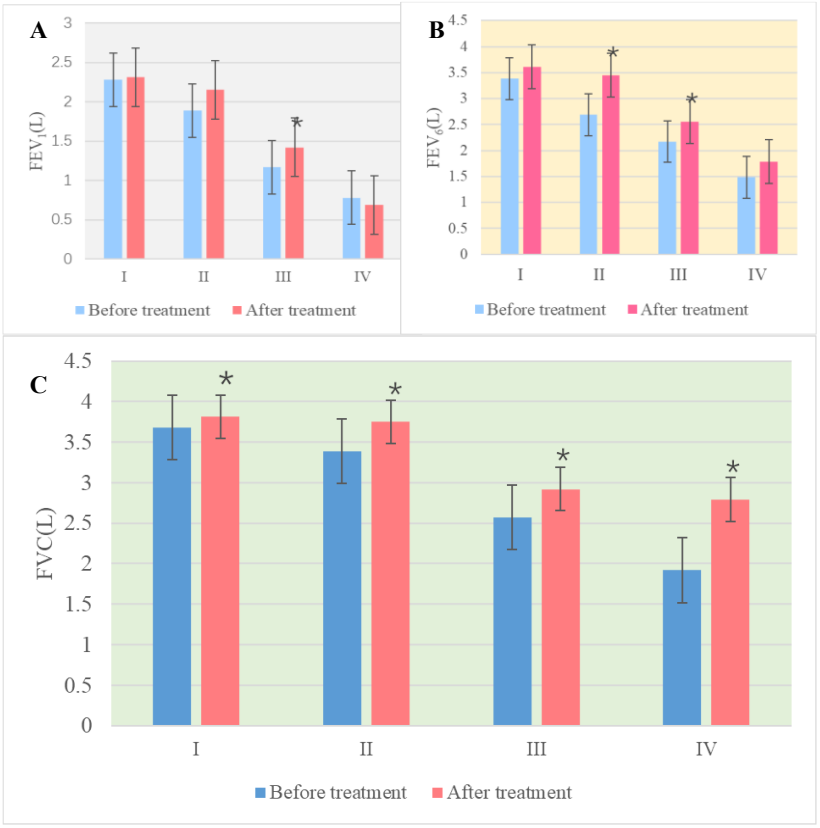

Figure 1. Changes in pulmonary function indexes in patients with different grades. *: $P < 0.05$ before and after treatment.

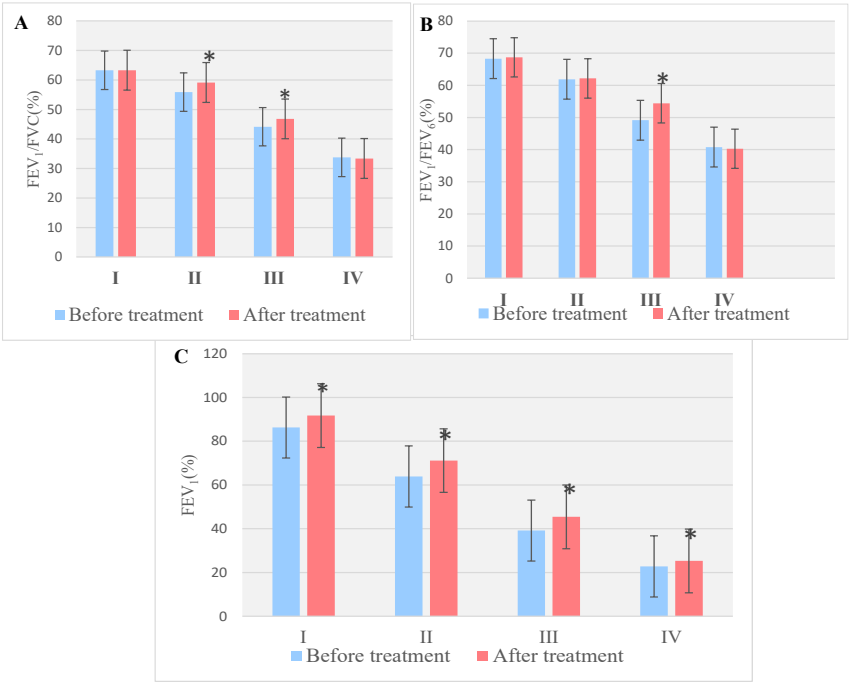

Figure 2. Changes in pulmonary function indexes FEV_1/FVC, FEV_1/FEV_6, and FEV_1 in patients with different grades. *: $P < 0.05$ before and after treatment.

Table 2. Comparison of inflammatory cells in patients with different grades.

	WBC (10^9/L)	PLT	CRP (mg/mL)	NEU%
I	6.32 ± 2.03	113.21	4.58 (8.56)	5.37 ± 2.61
II	6.81 ± 2.71	128.32	4.78 (11.02)	6.87 ± 2.01
III	7.31 ± 2.43	136.48	7.62 (12.81)	6.92 ± 2.31
IV	7.71 ± 2.17	171.43	4.19 (5.83)	6.39 ± 2.84
P	0.763	0.831	0.127	0.728

The FEV_1/FVC ratio (%) demonstrated no significant differences across groups either pre- or post-treatment (Figure 2A). In contrast, FEV_1/FEV_6 ratio (%) showed significant differences in the post-treatment tests across the three groups relative to their pre-treatment levels ($P < 0.05$) (Figure 2B). FEV_1 (%) showed a significant difference between pre- and post-treatment assessments ($P < 0.05$) (Figure 2C).

Correlation analysis across all severity levels

The link of FEV_6 with FVC was further analyzed at various severity levels, comparing pre- and post-treatment data. Notably, Pearson correlation analysis uncovered a robust positive link between FEV_6 and FVC with correlation coefficients R = 0.961 in pre-treatment and R = 0.947 in post-treatment. Both values exhibited significant differences ($P < 0.05$), reflecting a strong link between these two indices in assessing PF (Figure 3).

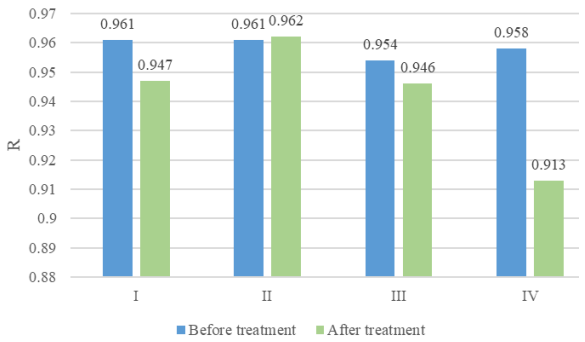

Figure 3. Correlation analysis of FEV_6 and FVC in patients with different grades.

The Pearson correlation analysis of FEV_1/FVC (%) with FEV_1/FEV_6 (%) pre- and post-treatment in cases with different grades demonstrated that FEV_1/FVC (%) showed a positive link with FEV_1/FEV_6 (%) (Figure 4).

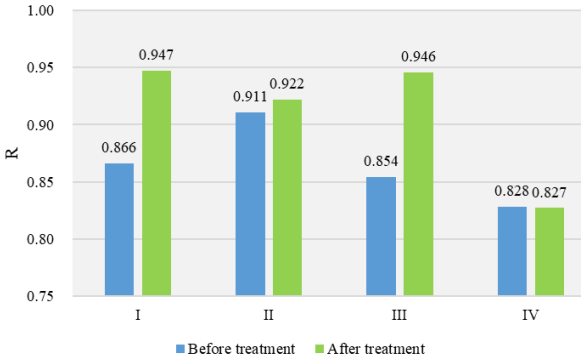

Figure. 4 Correlation analysis between FEV_1/FVC (%) and FEV_1/FEV_6 (%) in patients with different grades.

Comparative analysis of routine hematological parameters across COPD stages

The comparative analysis of routine hematological parameters showed that WBC count, PLT count, CRP level, and NEU%, had no significant differences among different stages of COPD (Table 2), which reflected that the variation in these parameters did not correlate with COPD's severity, emphasizing that these markers might not serve as reliable indicators of disease progression across the studied stages.

Differential analysis of LAA% across COPD stages at specific CT thresholds

The analysis of LAA% at diverse CT thresholds of -1,024, -960, -950, -940, -930, and -910 HU demonstrated significant inter-stage differences, particularly between IV and III groups. These differences were consistently evident across all

thresholds with Chi-square values ranging from 153.6 to 190.3, reflecting the robust statistical significance of the variations in LAA% across distinct COPD stages. The outcomes reflected the potential of CT-derived LAA% as a noticeable imaging biomarker for differentiating between COPD severity levels, particularly in advanced stages (Figure 5).

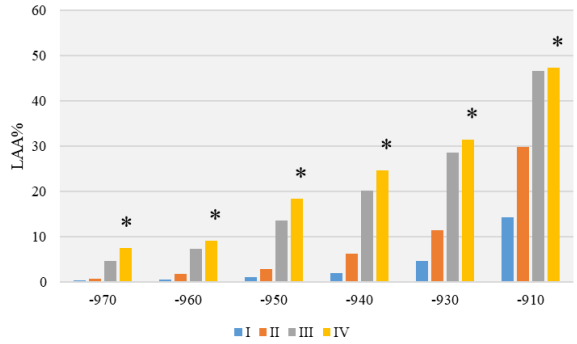

Figure 5. LAA% comparison results of different CT values for each grade. *: $P < 0.05$ compared with group III.

Comparative analysis of MMRC% across grades with diverse CT values

A remarkable escalation in CT values was noteworthy in IV group relative to the other three groups within the CT range of -1,024 to -910 HU (Figure 6).

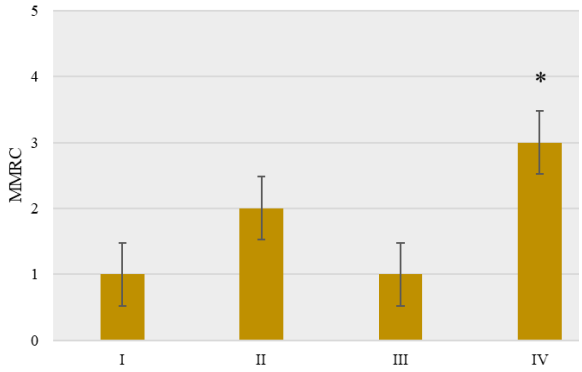

Figure 6. MMRC% comparison results of different CT values for each grade. *: $P < 0.05$ compared with group III.

Comparative analysis of LAA% across COPD grades at various CT thresholds

The significant differences in LAA% between grades II and I, grades III and II, and grades IV and III were observed ($P < 0.05$) when evaluated at CT attenuation values between -1,024 and -910 HU. (Figure 7).

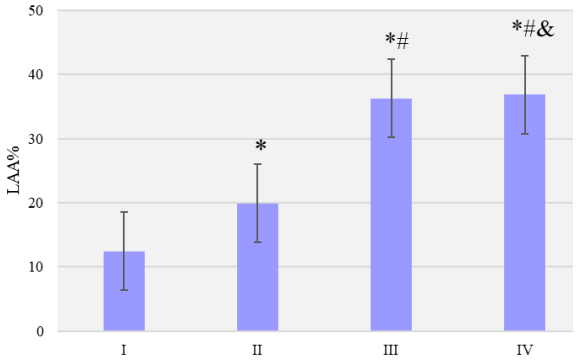

Figure 7. LAA% comparison results of different CT values for each grade. *: $P < 0.05$ compared with group I. #: $P < 0.05$ compared with group II. &: $P < 0.05$ compared with group III.

Discussion

COPD is a respiratory disorder characterized by a systemic chronic inflammatory response, which has a prolonged course and cannot be completely cured, requiring long-term management. COPD significantly impacts patients' physical and mental health, as well as their economic well-being [21]. The pathogenesis of COPD involves the release of various inflammatory factors and cells including tumor necrosis factor-alpha (TNF-α), interleukin-1 beta (IL-1β), interleukin-6 (IL-6), nuclear factor-kappa B (NF-κB), and other interleukins [22, 23]. This research examined the WBC count, PLT count, CRP concentrations, and NEU% among cases with diverse stages of COPD and found that there were no significant differences in the levels of WBC, PLT, CRP, and NEU% across the four COPD stages. COPD is a progressive disease, and emphysema can lead to its severe form. GOLD evaluates the severity of COPD based on the degree of airway obstruction. The clinical diagnosis of emphysema primarily relies on PFTs with CT being the common imaging method for diagnosis. Emphysema CT diagnosis is typically based on lung density with a standard

threshold of -950 Hounsfield units (HU) for low-density areas, though some studies use -960 HU. However, the classification of emphysema severity remains imprecise. Emphysema exerts a remarkable impact on COPD's severity, as the progressive destruction of lung parenchyma serves as a pivotal determinant in the trajectory of the disease. Numerous studies found that approximately 50% of cases with stage I and II COPD demonstrated varying degrees of emphysema with a predilection for more severe forms in the upper lung regions and adjacent to the hilum. Both qualitative and quantitative CT imaging have been employed to delineate COPD subtypes. Park *et al*. utilized a combined approach of visual and quantitative CT assessments to elucidate the diverse pathological mechanisms inherent to the heterogeneous subtypes of COPD [24]. The results of this study showed significant differences in LAA% between grades I and II, II and III, III and IV ($P < 0.05$) with CT values ranging from -1,024 to -910 HU. Inflammatory mediators are integral to the pathophysiology of airway mucosal epithelial damage in COPD, initiating a pathway of immune responses that lead to neutrophil infiltration and the subsequent hepatic synthesis of C-reactive protein [25]. Empirical evidence unveiled that the concentrations of these inflammatory biomarkers particularly in healthy individuals were noticeably attenuated relative to those in COPD cases with these elevations closely linked to the patients' diminished quality of life [26]. Previous studies on the cardiovascular sequelae of COPD consistently show that the disease causes significant cardiovascular manifestations including right ventricular dysfunction, arrhythmias, and coronary artery disease. The pathological features of COPD include elevated pulmonary artery pressure, pulmonary hyperinflation, endothelial dysfunction, and the systemic inflammatory response and exert a combined effect that either directly or indirectly exacerbates right ventricular workload. COPD is highly recognized as a multifaceted and heterogeneous disorder, characterized by divergent pathophysiological mechanisms, reflecting the necessity of the precise identification of disease subtypes through cutting-edge imaging biomarkers. Such diagnostic refinement could drive individualized therapeutic approaches, enhancing prognostic outcomes for patients. In this context, the exploration of CT imaging characteristics across varying stages of COPD severity holds remarkable clinical value. This research delineated the link of FEV_6 with FVC, both pre- and post-treatment, in cases classified by disease severity. Pearson correlation analysis uncovered a robust positive link of FEV_6 with FVC. Further, the link of the FEV_1/FVC ratio with FEV_1/FEV_6 percentage confirmed a significant positive link between these two variables across the different COPD grades. Consistently, Mokari-Yamchi *et al*. explored the CT pulmonary vascular parameters and disease severity in COPD, documenting notable differences in the clinical measures of disease progression, involving FEV_1, FVC, and FEV_1/FVC ratio, in cases with varying COPD severity and found that the duration of COPD, cross-sectional area, and the pulmonary artery to aorta ratio were remarkably linked to the degree of disease severity [27].

Conclusion

This research analyzed the alterations in pulmonary CT images and their link with PF indices in cases with stable COPD of varying grades. The severity of airflow limitation, small airway function, and diffusion capacity in COPD cases were found to be linked with specific characteristics observed in pulmonary CT images. Quantitative CT was confirmed to be effective in assessing the severity of emphysema particularly in COPD cases. Moreover, PF was significantly improved post-treatment, which had important implications for the management and progression of COPD. These results provided outstanding insights into COPD's diagnosis and therapy. However, the sample size in this study was relatively small and should be expanded in future research to provide more robust evidence.

References

1. Vogelmeier C, Román-Rodríguez M, Singh D, Han MK, Rodríguez-Roisin R, Fergusonet GT. 2020. Goals of COPD treatment: focus on symptoms and exacerbations. Respir Med. 166:105938.
2. Asensio V, Tomás A, Iglesias A, de Llano LP, del Pozo V, Cosíoet BG, *et al*. 2020. Eosinophilic COPD patients display a distinctive serum miRNA profile from asthma and non-eosinophilic COPD. Arch Bronconeumol (Engl Ed). 56(4):234-241.
3. Waatevik M, Frisk B, Francisco G, Hardie JA, Bakke P, Eagan TM, *et al*. 2021. CT-defined emphysema in COPD patients and risk for change in desaturation status in 6-min walk test. Respir Med. 187:106542.
4. Vogelmeier C, Criner G, Martinez F, Anzueto A, Barnes PJ, Bourbeau J, *et al*. 2017. Global strategy for the diagnosis, management, and prevention of chronic obstructive lung disease 2017 Report. GOLD Executive Summary. Am J Respir Crit Care Med. 195(5):557-582.
5. Zhu B, Wang Y, Ming J, Chen W, Zhang L. 2018. Disease burden of COPD in China: a systematic review. Int J Chron Obstruct Pulmon Dis. 13:1353-1364.
6. Ley-Zaporozhan J, Ley S, Hans-Ulrich K. 2008. Morphological and functional imaging in COPD with CT and MRI: Present and future. Eur Radiol. 18(3):510-521.
7. Bhatt S, Balte P, Schwartz J, Cassano PA, Couper D, Jacobs GR, *et al*. 2019. Discriminative accuracy of FEV_1: FVC thresholds for COPD-related hospitalization and mortality. JAMA. 321(24):2438-2447.
8. Chung K, Jung J, Park M, Kim YS, Kim SK, Chang J, *et al*. 2016. Cut-off value of FEV_1/FEV_6 as a surrogate for FEV_1/FVC for detecting airway obstruction in a Korean population. Int J Chron Obstruct Pulmon Dis. 11:1957-1963.
9. Devereux G, Cotton S, Fielding S, McMeekin N, Barnes PJ, Briggset A, *et al*. 2018. Effect of Theophylline as adjunct to inhaled corticosteroids on exacerbations in patients with COPD: A randomized clinical trial. JAMA. 320(15):1548-1559.
10. Zhu M, Ye M, Wang J, Ye L, Jin M. 2020. Construction of potential miRNA-mRNA regulatory network in COPD plasma by bioinformatics analysis. Int J Chron Obstruct Pulmon Dis. 15:2135-2145.
11. Ritchie A, Wedzicha J. 2020. Definition, causes, pathogenesis, and consequences of chronic obstructive pulmonary disease exacerbations. Clin Chest Med. 41(3):421-438.
12. Terry P, Dhand R. 2020. Inhalation therapy for stable COPD: 20 Years of GOLD reports. Adv Ther. 37(5):1812-1828.
13. Mouronte-Roibás C, Leiro-Fernández V, Fernández-Villar A, Botana-Rial M, Ramos-Hernández C, Ruano-Ravina A. 2016. COPD, emphysema and the onset of lung cancer. A systematic review. Cancer Lett. 382(2):240-244.
14. Brandsma C, Vries M, Costa R, Woldhuis RR, Königshoff M, Timens W. 2017. Lung ageing and COPD: Is there a role for ageing in abnormal tissue repair? Eur Respir Rev. 26(146):170073.
15. Rogliani P, Ora J, Puxeddu E, Cazzola M. 2016. Airflow obstruction: is it asthma or is it COPD? Int J Chron Obstruct Pulmon Dis. 11:3007-3013.
16. Roffel M, Bracke K, Heijink I, Maes T. 2020. miR-223: A key regulator in the innate immune response in asthma and COPD. Front Med (Lausanne). 7:196.
17. He S, Chen D, Hu M, Zhang L, Liu C, Traini D, *et al*. 2019. Bronchial epithelial cell extracellular vesicles ameliorate epithelial-mesenchymal transition in COPD pathogenesis by alleviating M2 macrophage polarization. Nanomedicine. 18:259-271.
18. Yang I, Brown J, George J, Jenkins S, McDonald CF, McDonald VM, *et al*. 2017. COPD-X Australian and New Zealand guidelines for the diagnosis and management of chronic obstructive pulmonary disease: 2017 update. Med J Aust. 207(10):436-442.
19. Hirai K, Shirai T, Shimoshikiryo T, Ueda M, Gon Y, Maruoka S, *et al*. 2021. Circulating microRNA-15b-5p as a biomarker for asthma-COPD overlap. Allergy. 76(3):766-774.
20. Lacedonia D, Pia P, Foschino-Barbaro M, Scioscia G, Carpagnano GE. 2017. Expression profiling of miRNA-145 and miRNA-338 in serum and sputum of patients with COPD, asthma, and asthma-COPD overlap syndrome phenotype. Int J Chron Obstruct Pulmon Dis. 12:1811-1817.
21. Kubincová A, Takáč P, Kendrová L, Joppa P, Mikuľáková W. 2018. The effect of pulmonary rehabilitation in mountain environment on exercise capacity and quality of life in patients with Chronic Obstructive Pulmonary Disease (COPD) and chronic bronchitis. Med Sci Monit. 24:6375-6386.
22. Donnell D, Milne K, James M, de Torres JP, Neder JA. 2020. Dyspnea in COPD: New mechanistic insights and management implications. Adv Ther. 37(1):41-60.
23. Zhang J, Xu Z, Kong L, Gao H, Zhang Y, Zheng Y, *et al*. 2020. miRNA-486-5p promotes COPD progression by targeting HAT1 to regulate the TLR4-Triggered inflammatory response of alveolar macrophages. Int J Chron Obstruct Pulmon Dis. 15:2991-3001.
24. Park J, Brian D, Crapo J, Make BJ, Regan EA, Humphries S, *et al*. 2020. Subtyping COPD by using visual and quantitative CT imaging features. Chest. 157(1):47-60.
25. Jones B, Donovan C, Liu G, Chimankar V, Harrison CL, Wiegman, CH, *et al*. 2017. Animal models of COPD: What do they tell us? Respirology. 22(1):21-32.
26. Yang T, Chen C, Chen Z. 2021. The CT pulmonary vascular parameters and disease severity in COPD patients on acute exacerbation: a correlation analysis. BMC Pulm Med. 21(1):34.
27. Mokari-Yamchi A, Jabbari M, Sharifi A, Barati M, Kheirouri S. 2019. Low FEV1 is associated with increased risk of Cachexia in COPD patients. Int J Chron Obstruct Pulmon Dis. 14:2433-2440.