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**ORIGINAL ARTICLE**

# Quantitative CT Assessment of Emphysema and Its Relationship with Disease Severity

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## ABSTRACT

**Background:** Emphysema is a key structural component of chronic obstructive pulmonary disease (COPD) and a significant driver of the disease burden and disease progression. While conventional spirometry can give only a limited amount of information about regional lung destruction, whereas quantitative computed tomography (CT) offers objective assessment of emphysema severity.

**Objective:** To evaluate quantitative CT measures of emphysema and determine their relationship with clinical, functional, and radiological indicators of disease severity in patients with COPD.

**Methods**: This was a cross-sectional study of 100 patients with COPD (GOLD diagnosis). PFT and HRCCT of the chest were performed in all participants. Quantitative measurement of emphysema was made by density mask analysis and the areas with low attenuation were below −950 HU, which were then used to calculate the emphysema index, the mean lung density and the total lung volume. Severity of the disease was determined by $FEV_1$ percentage predicted, GOLD stage, dyspnea score on the modified MRC, oxygen saturation and exacerbation frequency. The statistical analysis were correlation and group comparison tests.

**Results:** The emphysema index mean value was 18.9 ± 10.7%. There was a significant negative correlation between quantitative CT and $FEV_1$ (% predicted) ($r = -0.72$, $p < 0.001$) and $FEV_1$/FVC ratio. Increased dyspnea scores, decreased oxygen saturation and increased exacerbation burden were significantly associated with higher emphysema burden. Patients with severe emphysema had significant impairment of pulmonary function and clinical outcomes compared with patients with mild disease ($p < 0.001$).

**Conclusion:** Quantitative CT evaluation of emphysema is a good and reliable index of COPD severity. It has shown a strong correlation with functional impairment and clinical outcomes and should be used in conjunction with spirometry in the comprehensive evaluation, phenotyping and management planning of the disease.

**Keywords**: COPD, emphysema, quantitative computed tomography (CT), lung function, GOLD stage and imaging biomarkers.

## INTRODUCTION

Chronic obstructive pulmonary disease (COPD) is a serious condition in the lungs and is one of the leading causes of morbidity and mortality around the globe. It is defined by the presence of a longstanding airflow limitation, which is caused by small airway disease and parenchymal destruction.[1] Emphysema is an important pathological component of COPD characterized by permanent enlargement of air spaces distal to terminal bronchioles with destruction of the alveolar walls.[2] The loss of elasticity and the decrease in the gas-exchange surface area are important factors in the development of respiratory dysfunction, exercise intolerance and decreased quality of life. [3]

The diagnosis and evaluation of emphysema was mostly based on pulmonary function tests (PFTs), especially spirometry. Spirometry is the main test used to assess airflow limitation, but it only measures the overall lung function and does not measure the amount, distribution or severity of structural lung damage.[4] Radiological patterns, however, may vary significantly between patients with similar spirometric values and clinical responses may be quite different as well, thus necessitating a more specific way to characterize the disease. The evaluation of chronic lung diseases has been revolutionized by advances in imaging technology, especially computed tomography (CT).[5] HRCT is an imaging modality that allows for the visualization of the lung parenchyma at a high level of resolution and is now the most sensitive imaging technique for emphysematous change. [6]

CT technology is now available for quantitative assessment of emphysema, beyond visual assessment, based on the percentage of low attenuation areas and calculation of lung density parameters.[7] These objective measurements offer reproducible markers of emphysema burden and help to better understand the severity of the disease. The quantitative CT assessment has become more and more interesting since it can provide information on the degree of heterogeneity of emphysema.[8]

Emphysematous destruction is heterogeneous and can affect symptoms, pulmonary function, exercise capacity, exacerbation rates and prognosis. Numerous studies have shown that quantitative CT indices are correlated with the clinical severity markers of disease, such as forced expiratory volume in one second ($FEV_1$), diffusion capacity, dyspnea score and health related quality of life.[9] These results indicate that in addition to traditional physiological tests, CT-based metrics could be useful in risk stratification. In addition, quantitative CT is becoming increasingly significant with regard to therapeutic decision making.[10]

Properly quantifying the severity of emphysema helps to select candidates for interventions like lung volume reduction surgery, bronchoscopic lung volume reduction surgery, and pharmacological advances.[11] Additionally, quantitative imaging biomarkers have been found to have promise in tracking disease progression and assessing treatment response over time.[12] Although quantitative CT has been increasingly adopted, there is still a lack of knowledge regarding the clinical significance of the different presentations of the disease in different sub-populations. Improved diagnostic accuracy, the ability to create personalized treatment plans and enhancing patient outcomes could be achieved by understanding the correlation between CT-derived emphysema indices and known measures of disease severity. [13]

Thus, the present study is designed to quantify emphysema by computed tomography and to analyze the correlation between emphysema and severity of chronic obstructive pulmonary disease patients. This study aims to determine the value of quantitative

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imaging in comprehensive assessment and management of the disease by correlating the findings of the imaging with clinical and functional parameters.

## MATERIALS AND METHODS

This multi-center cross-sectional observational study was conducted in the Department of Radiology in collaboration with the Department of Pulmonology at tertiary care teaching hospitals. The study duration was of twelve months from Feb 2022 to Feb 2023. A total of 100 patients diagnosed with chronic obstructive pulmonary disease (COPD) were enrolled through consecutive sampling. The diagnosis of COPD was established according to the Global Initiative for Chronic Obstructive Lung Disease (GOLD) criteria, based on clinical history, physical examination and spirometric evidence of persistent airflow limitation with a post-bronchodilator $FEV_1$/FVC ratio of less than 0.70. Patients aged 40 years and above who underwent chest computed tomography (CT) and pulmonary function testing within one month of each other were included in the study. Patients with a history of pulmonary tuberculosis, interstitial lung disease, bronchiectasis, lung malignancy, previous lung surgery, acute COPD exacerbation within the preceding six weeks, or poor-quality CT images were excluded.

Demographic and clinical data including age, sex, smoking status, smoking index, duration of symptoms, comorbid conditions and history of exacerbations were recorded using a structured proforma. The severity of dyspnea was assessed using the Modified Medical Research Council (mMRC) dyspnea scale. Oxygen saturation was measured using pulse oximetry under resting conditions.

Pulmonary function testing was performed using a standardized computerized spirometer according to the recommendations of the American Thoracic Society and the European Respiratory Society. Parameters recorded included forced expiratory volume in one second ($FEV_1$), forced vital capacity (FVC), $FEV_1$/FVC ratio and percentage predicted $FEV_1$. Based on post-bronchodilator $FEV_1$ values, patients were classified into GOLD stages I, II, III, and IV.

All participants underwent non-contrast high-resolution computed tomography (HRCT) of the chest using a multidetector CT scanner. Scans were acquired in the supine position during full inspiratory breath-hold. Imaging parameters included a tube voltage of 120 kVp, automatic tube current modulation, slice thickness of 1–1.25 mm, and high-resolution reconstruction algorithms. The acquired images were transferred to dedicated image-analysis software for quantitative evaluation.

Quantitative assessment of emphysema was performed using density mask analysis. Areas with attenuation values below −950 Hounsfield Units (HU) on inspiratory CT scans were identified as emphysematous regions. The percentage of low attenuation area (LAA%), mean lung density (MLD), total lung volume (TLV) and emphysema index (14) were calculated. The emphysema index was defined as the percentage of lung volume occupied by voxels with attenuation values below −950 HU. Based on the emphysema index, patients were categorized into mild, moderate and severe emphysema groups.

Disease severity was assessed using multiple clinical and functional indicators, including GOLD stage, $FEV_1$ percentage predicted, mMRC dyspnea score, frequency of COPD exacerbations during the preceding year and resting oxygen saturation. Correlations between quantitative CT parameters and these indicators of disease severity were subsequently evaluated.

All data were entered and analyzed using Statistical Package for Social Sciences (SPSS) version 26. Continuous variables were expressed as mean ± standard deviation whereas categorical variables were presented as frequencies and percentages. Comparisons between groups were performed using Student's t-test, one-way analysis of variance (ANOVA), or Chi-square test as appropriate. Pearson's correlation analysis was used to determine the relationship between quantitative CT measurements and pulmonary function parameters. A p-value of less than 0.05 was considered statistically significant.

## RESULTS

A total of 100 patients with COPD were included in the study. The mean age of the study population was 63.8 ± 9.7 years. Males constituted the majority of participants (78%), while 22% were females. Most patients had a history of smoking (72%), and the mean smoking index was 412.6 ± 145.3.

Table 1: Demographic and Clinical Characteristics of the Study Population (n=100)

| Variable | Value |
|---|---|
| Age (years), Mean ± SD | 63.8 ± 9.7 |
| Male, n (%) | 78 (78.0) |
| Female, n (%) | 22 (22.0) |
| Smokers, n (%) | 72 (72.0) |
| Smoking Index, Mean ± SD | 412.6 ± 145.3 |
| Duration of Symptoms (years), Mean ± SD | 8.4 ± 3.6 |
| mMRC Dyspnea Score, Mean ± SD | 2.7 ± 0.9 |
| Oxygen Saturation (%), Mean ± SD | 91.8 ± 4.5 |

The distribution of patients according to GOLD spirometric classification is presented in Table 2. Most patients belonged to GOLD stage II (38%) and stage III (34%).

Table 2: Distribution of Patients According to GOLD Stage

| GOLD Stage | Frequency (n) | Percentage (%) |
|---|---|---|
| Stage I (Mild) | 12 | 12.0 |
| Stage II (Moderate) | 38 | 38.0 |
| Stage III (Severe) | 34 | 34.0 |
| Stage IV (Very Severe) | 16 | 16.0 |

Pulmonary function parameters showed a progressive decline in lung function among study participants.

Table 3: Pulmonary Function Test Parameters

| Parameter | Mean ± SD |
|---|---|
| $FEV_1$ (% Predicted) | 48.6 ± 17.8 |
| FVC (% Predicted) | 68.3 ± 14.5 |
| $FEV_1$/FVC Ratio (%) | 53.7 ± 8.6 |

Quantitative CT analysis demonstrated varying degrees of emphysematous destruction among participants. The mean emphysema index was 18.9 ± 10.7%.

Table 4: Quantitative CT Parameters

| Parameter | Mean ± SD |
|---|---|
| Low Attenuation Area (LAA%) | 21.5 ± 11.8 |
| Mean Lung Density (HU) | -875.4 ± 38.7 |
| Total Lung Volume (L) | 5.9 ± 1.3 |
| Emphysema Index (%) | 18.9 ± 10.7 |

Based on quantitative CT findings, patients were categorized according to emphysema severity. Moderate emphysema was the most frequent category.

Table 5: Distribution of Patients According to Emphysema Severity

| Emphysema Severity | Frequency (n) | Percentage (%) |
|---|---|---|
| Mild (<10%) | 28 | 28.0 |
| Moderate (10–25%) | 46 | 46.0 |
| Severe (>25%) | 26 | 26.0 |

A significant inverse relationship was observed between emphysema index and pulmonary function parameters. Patients with severe emphysema demonstrated substantially lower $FEV_1$ values compared to those with mild emphysema.

Table 6: Relationship Between Emphysema Severity and Pulmonary Function

| Emphysema Severity | $FEV_1$ (% Predicted) Mean ± SD | p-value |
|---|---|---|
| Mild | 64.8 ± 11.3 | |
| Moderate | 47.2 ± 10.6 | |
| Severe | 29.5 ± 8.7 | <0.001 |

The emphysema index showed significant correlations with disease severity indicators. Higher emphysema burden was associated with lower $FEV_1$ values, higher dyspnea scores, and lower oxygen saturation levels.

Table 7: Correlation of Quantitative CT Parameters with Disease Severity

| Variable | Correlation Coefficient (r) | p-value |
|---|---|---|
| $FEV_1$ (% Predicted) | -0.72 | <0.001 |
| $FEV_1$/FVC Ratio | -0.65 | <0.001 |
| mMRC Dyspnea Score | +0.61 | <0.001 |
| Oxygen Saturation | -0.58 | <0.001 |
| Annual Exacerbations | +0.54 | <0.001 |

Patients with severe emphysema experienced a higher frequency of COPD exacerbations and more pronounced dyspnea compared to patients with mild disease.

Table 8: Clinical Severity According to Emphysema Category

| Variable | Mild | Moderate | Severe | p-value |
|---|---|---|---|---|
| mMRC Score | 1.8 ± 0.7 | 2.6 ± 0.8 | 3.5 ± 0.6 | <0.001 |
| Oxygen Saturation (%) | 95.1 ± 2.3 | 91.7 ± 3.4 | 87.2 ± 4.1 | <0.001 |
| Exacerbations/Year | 1.1 ± 0.6 | 2.0 ± 0.8 | 3.4 ± 1.1 | <0.001 |

Overall, quantitative CT-derived emphysema measurements demonstrated strong correlations with pulmonary function impairment, symptom burden, and clinical severity. Increasing emphysema index was associated with worsening airflow limitation, greater dyspnea, lower oxygen saturation, and increased frequency of exacerbations.

## DISCUSSION

In this study, emphysema was measured quantitatively using computed tomography (CT) and correlated this measurement with patients' disease status in patients with chronic obstructive pulmonary disease (COPD). Our results showed that there was significant correlation between the CT-measured emphysema parameters and spirometric impairment, symptom burden, oxygen desaturation and exacerbation frequency. These observations further confirm the increasing importance of quantitative CT as an objective lung imaging biomarker of lung structural damage and disease severity in COPD.

Most of the subjects in the present study were male smokers of old age. This age-sex distribution is similar to that of the COPD epidemiology, in which the main risk factor for developing emphysema is tobacco smoking. Lynch et al. found similar results, that older smokers have more emphysematous changes, with a particular focus on the negative effects of tobacco on lung parenchymal destruction.[15] The mean emphysema index was 18.9% and almost one-fourth of patients had severe emphysema, as indicated by quantitative CT analysis. The results are similar to those that were observed in the COPD Gene study, which showed that the extent of emphysema was significantly different in individuals with the same spirometric classification. This variability points to the fact that spirometry is not the best method to describe the structural components of COPD and demonstrates the importance of CT-based COPD phenotyping. [16]

The emphysema index and $FEV_1$ % predicted showed a significant negative correlation which was the main determinant in this study ($r = -0.72$, $p<0.001$). PFT measures were significantly reduced in patients with severe emphysema compared with patients with mild disease. The findings of the study are also consistent with the findings of Mohamed Hoesein et al. which showed that higher low-attenuation areas on CT were correlated with worsening airflow limitation and loss of lung function. This close relationship between structural and functional impairments in emphysema has been explained by the fact that loss of elastic recoil and destruction of alveolar walls are direct causes of airflow obstruction.[14]

This study also showed that there was significant correlation between CT derived emphysema burden and clinical symptoms. Increased mMRC dyspnea scores were seen with increased emphysema indices. This is similar to what was reported by Martinez et al. who have reported breathlessness in patients with extensive emphysematous changes, but with similar spirometric measurements. This discovery implies that structural destruction in the lungs can be a factor that affects symptom severity in addition to the usual physiological tests.[11]

The other major finding was that of a correlation between emphysema severity and resting oxygen saturation. Severe emphysema patients had significantly lower oxygen saturation levels in comparison to mild emphysema patients. This relationship is biologically plausible because as alveoli continue to be destroyed, there is a decrease of area for gas exchange, which means less oxygen can diffuse.

A similar association between quantitative CT measures and gas exchange abnormalities and exercise limitation have been reported from COPD patients by Sverzellati et al.[17] In our study, the more emphysema burdens, the more frequent the exacerbations. Patients with the most severe emphysema had more exacerbations in the year before the study than patients with less severe emphysema. This discovery is in line with other research that indicated emphysema-predominant COPD is a unique phenotype, with higher morbidity and health care utilization. Extensive emphysema has been reported to be associated with increased risk for acute exacerbation and disease progression, highlighting the prognostic value of emphysema measured by CT.[18]

Our results also support the notion of COPD being a heterogeneous disease. CT scans of the lungs showed different amounts of emphysema in patients with the same GOLD stage. This observation is in line with earlier findings showing that the disease heterogeneity cannot be completely captured by spirometry. Quantitative CT can provide further quantitative information about the degree and distribution of parenchymal destruction, which can aid in a more personalized evaluation of the patient and thus management.[19] The implications of quantitative CT are significant. In addition to diagnosis, measurements of the CT emphysema may help determine patients' eligibility for lung volume reduction surgery, bronchoscopic lung volume reduction therapy and other advanced therapies. In addition, objective quantification of emphysema burden may be useful for monitoring disease progression and for evaluating response to treatment, both in clinical practice and in research.

The following are some limitations of the present study that should be recognized. First, the cross-sectional design does not allow for causal conclusions to be drawn or appropriate conclusions to be made regarding the progression of the disease over time. Second, the study took place in a single center with a small number of patients; the results of the study may not be generalizable on this point. Thirdly, other parameters like diffusion capacity and exercise tolerance were not assessed. Multicentric prospective studies with follow-up data will give a better picture of the value of quantitative CT in the management of COPD in the future.

The study shows that quantitative CT emphysema analysis is useful for obtaining information about the severity of the disease and clinical prognosis. There are strong relationships between pulmonary function, symptom burden, oxygenation status, exacerbation frequency and CT-derived emphysema indices, which justify the use of quantitative imaging in the clinical management of COPD. This strategy could help to create more precise disease phenotyping, to better understand the disease prognosis, and to guide tailored therapeutic interventions.

## CONCLUSION

The present study demonstrates that quantitative CT assessment provides a reliable and objective method for evaluating emphysema burden in patients with COPD. CT-derived emphysema indices showed strong and consistent correlations with spirometric impairment, symptom severity, oxygen saturation, and frequency of exacerbations, highlighting their value in reflecting both structural and functional disease severity. These findings support the limitation of spirometry alone in fully characterizing COPD and emphasize the complementary role of imaging-based biomarkers. Quantitative CT can therefore play an

important role in disease phenotyping, severity stratification, and potentially guiding individualized management strategies. Incorporating quantitative CT into routine clinical evaluation may enhance early identification of high-risk patients and improve overall disease monitoring and prognostication.

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