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Research Article

Quantitative Radiological Anatomy of Pulmonary Parenchyma in Chronic Obstructive Pulmonary Disease: A High-Resolution Ct Based Morphometric Study

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ABSTRACT
Objective: To evaluate the quantitative radiological anatomy of the pulmonary parenchyma in COPD using HRCT-based morphometric analysis.
Materials and Methods: This cross-sectional study included 60 clinically stable COPD patients aged 40–80 years. HRCT scans were performed using a standardized protocol during full inspiration. Quantitative parameters assessed included bronchial wall thickness and luminal diameter of bronchi, mean lung density (MLD), low attenuation areas (LAA < −950 HU), emphysema index (EI), total lung volume (TLV) and zonal distribution of disease. Data were analyzed using statistical softwareand correlations between variables were determined.
Results: The mean age of patients was 61.4 ± 9.2 years, with a predominance of males (70%). Bronchial wall thickness was increased (2.8 ± 0.6 mm) while luminal diameter was reduced (4.9 ± 1.1 mm). Mean lung density was decreased (−856.3 ± 34.5 HU)and low attenuation areas constituted 28.7 ± 10.2% of lung volume. The emphysema index was 30.2 ± 11.5% and total lung volume was elevated (5890 ± 820 mL), indicating hyperinflation. Zonal analysis showed a predominance of disease in the upper lung regions. Significant correlations were observed between emphysema index and mean lung density ($r = -0.72$, $p < 0.001$) as well as total lung volume ($r = 0.64$, $p < 0.001$).
Conclusion: HRCT-based quantitative analysis provides a comprehensive and objective evaluation of structural lung changes in COPD. The combined assessment of airway and parenchymal parameters enhances understanding of disease severity and distribution, supporting its role in improved diagnosis, phenotyping and management of COPD.

Keywords: COPD, HRCT, Emphysema Index, Lung Density, Airway Anatomy, Morphometric Analysis.

INTRODUCTION

Chronic obstructive pulmonary disease (COPD) causes difficulty in breathing that gradually worsens over time. Itis a progressive and heterogenous respiratory disease which is mainly caused by exposure to harmful substances such as cigarette smoke, air pollution and occupational dust.(Houghton et al., 2008) Chronic obstructive pulmonary disease is one of the leading causes of illness and death worldwide. Traditionally, doctors assess COPD using breathing tests like spirometry. (Byrne et al., 2015)Spirometry measures how much air a person can inhale and exhale. However, these tests only show how well the lungs are functioning and do not explain what structural changes are happening inside the lungs.(Hesselbacher et al., 2011)
With the advancement of imaging techniques, especially high-resolution computed

tomography (HRCT), it has become possible to directly look at the detailed structure of the lungs. HRCT provides clear images of both the airways and lung tissue (parenchyma).(Cosio Piqueras and Cosio, 2001) It helps doctors to understand how the disease affects different parts of the lungs. More recently, HRCT is not only used to look at the lungs visually but also to measure different features of lung structure. This is known as quantitative or morphometric analysiswhich gives more precise and objective information.(Hogg, 2008)

One of the important aspects of COPD is the change in airway anatomy. Increased bronchial wall thickness is often associated with chronic bronchitis and airway-dominant phenotypes whereas reduced luminal diameter contributes directly to airflow obstruction.(Ji et al., 2023)In case of COPD, the walls of the bronchi (airways) may become thick due to inflammation and scarring. At the same time, the inner space (lumen) of these airways may become narrow.(Saure et al., 2016)Using HRCT, it is possible to measure bronchial wall thickness and the luminal diameter of bronchi. These measurements help in understanding how much the airways are affected and how this contributes to airflow limitation in COPD patients.(Miller et al., 2019)

Another key feature of COPD is damage to the lung tissue itself especially in patients with emphysema. This damage leads to the destruction of the tiny air sacs (alveoli). This in turn causes the lungs to lose their normal structure and function. (Gietema et al., 2013)HRCT helps in measuring lung density using Hounsfield Units (HU). Areas of the lung with very low density are called low attenuation areas (less than −950 HU).(Tho et al., 2015) Lung density indicates regions where the lung tissue has been destroyed. In addition, the mean lung density gives an overall idea of how healthy or damaged the lung tissue is. Lower mean lung density usually means more severe disease.(Schroeder et al., 2013)

The emphysema index is another useful measurement obtained from HRCT scans. It shows the percentage of the lung that is affected by low attenuation areas. In simple terms, it tells us how much of the lung has been damaged by emphysema.(Grydeland et al., 2010) A higher emphysema index means more severe destruction of lung tissue. This measurement is very helpful in comparing different patients and also in tracking how the disease progresses over time.(Nambu et al., 2016)

COPD also affects the size and volume of the lungs. Many patients develop hyperinflationwhere the lungs become over-expanded due to the trapped air. HRCT allows accurate measurement of total lung volume. (Heathcote et al., 2011)It also helps in studying how the disease is distributed in different parts of the lungs which is known as zonal distribution. The lungs can be divided into upper, middleand lower zones to see where the damage is more severe. For example, emphysema is often more prominent in the upper parts of the lungs. Understanding this distribution is important because it can influence treatment decisions and disease management.(Baraldo et al., 2012)

In recent years, computer-based software has made it easier to perform these measurements accurately and consistently. This reduces errors and differences between observers. However, some challenges still exist such as differences in CT scan techniques and patient-related factors like breathing during the scan.(Kliment et al., 2015) Despite these limitations, continuous improvements in technology are making HRCT a more reliable and widely used tool.

The application of quantitative HRCT in clinical practice is not without limitations. Factors such as radiation exposure, variability in imaging protocols and the need for specialized software and expertise may pose challenges to widespread implementation.(Hartley et al., 2016) Additionally, the interpretation of quantitative data requires careful consideration of confounding factors such as age, smoking history which may influence lung density and structure. (Kallieri et al., 2016)

HRCT-based quantitative analysis provides a detailed and practical way to study the structural changes in COPD. It is better to understand the disease by focusing on important variables such as bronchial wall thickness, luminal diameter, low attenuation areas, mean lung density, emphysema index, total lung volumeand zonal distribution. This helps in improving diagnosis, assessing severityand planning more effective treatment strategies for patients with COPD.

MATERIALS AND METHODS

This cross-sectional, observational study was conducted to evaluate the quantitative radiological anatomy of the pulmonary parenchyma in patients with chronic

obstructive pulmonary disease (COPD) using high-resolution computed tomography (HRCT). The study was carried out in the Department of Radiology in collaboration with the Department of Pulmonology at multiple tertiary care hospitals. The study was conducted for a period of 6 months from July 2025 to December 2025. Ethical approval for the study was obtained from the institutional review board of the hospital.Informed consent was taken from all participants. Patient confidentiality was strictly maintained throughout the research process.

A total of 60 patients diagnosed with COPD were included in the study. The diagnosis of COPD was based on clinical history, physical examinationand spirometric confirmation (post-bronchodilator $FEV_1/FVC < 0.70$). Patients aged between 40 and 80 years of either gender were enrolled. Only those patients who were clinically stable at the time of imaging were included.

Patients with a history of other significant lung diseases such as bronchial asthma, interstitial lung disease, pulmonary tuberculosis, lung malignancy or previous thoracic surgery were excluded from the study. In addition, patients with acute exacerbation of COPD, severe cardiac illnessor poor CT image quality were also excluded to avoid bias in quantitative analysis.

All patients underwent HRCT chest scanning using a multidetector CT scanner. Scans were performed in the supine position during full inspiration to ensure optimal lung expansion. Standard HRCT protocol was followed with thin-section slices (1–1.5 mm thickness), high spatial resolution reconstruction algorithm and no contrast administration. Images were obtained from lung apices to bases and were reconstructed in axial sections for analysis.

Quantitative analysis of HRCT images was performed using dedicated image analysis software. The following variables were assessed:

Airway anatomy was evaluated by measuring bronchial wall thickness and luminal diameter of segmental bronchi. Measurements were taken at standardized anatomical levels. Proper care was taken to ensure that bronchi were assessed in cross-section to avoid measurement errors. The wall thickness was calculated as the distance between the inner and outer bronchial wall margins.Luminal diameter was measured as the internal airway width.

Lung density parameters were assessed by calculating mean lung density (MLD) and identifying low attenuation areas (LAA). Low attenuation areas were defined as regions with attenuation values less than −950 Hounsfield Units (HU). Automated threshold-based segmentation techniques were used to identify and quantify these areas across the entire lung field.

The emphysema index (EI) was calculated as the percentage of total lung volume occupied by low attenuation areas (LAA < −950 HU). This provided an objective measure of the extent of emphysematous changes within the lungs.

Total lung volume (TLV) was measured using volumetric analysis tools within the software. The lungs were automatically segmented and the total volume was calculated in cubic centimeters. In addition, zonal distribution of lung involvement was assessed by dividing each lung into three regions: upper, middle and lower zones. Quantitative parameters such as LAA percentage and mean lung density were analyzed separately for each zone to determine regional variation in disease severity.

All measurements were performed by two experienced radiologists independently to minimize observer biasand the average of the readings was used for final analysis.

The collected data were entered and analyzed using statistical software SPSS version 22. Quantitative variables such as bronchial wall thickness, luminal diameter, mean lung density, emphysema index and total lung volume were expressed as mean ± standard deviation. Qualitative variables were presented as frequencies and percentages. Correlation analysis was performed to assess the relationship between different radiological parameters. A p-value of less than 0.05 was considered statistically significant.

RESULTS

A total of 60 patients with clinically and spirometrically confirmed COPD were included in this study. The mean age of the patients was 61.4 ± 9.2 yearswith a male predominance (70%). Quantitative HRCT analysis was successfully performed in all patients. The measured variables included airway anatomy, lung density parameters, emphysema index, total lung volume and zonal distribution.

Table 1: Demographic Characteristics of Study Population (N = 60)

Variable	Value
Age (years)	61.4 ± 9.2
Male	42 (70%)
Female	18 (30%)
Smoking history	46 (76.7%)
Non-smokers	14 (23.3%)

The study population mainly consisted of older adults with a higher proportion of males and smokers.This is consistent with known risk factors for COPD.

Table 2: Airway Anatomy Parameters on HRCT

Parameter	Mean ± SD
Bronchial wall thickness (mm)	2.8 ± 0.6
Luminal diameter of bronchi (mm)	4.9 ± 1.1

Bronchial wall thickness was increased while luminal diameter was relatively reduced, indicating airway remodeling and narrowing in COPD patients.

Table 3: Lung Density Parameters

Parameter	Mean ± SD
Mean lung density (HU)	-856.3 ± 34.5
Low attenuation area (< -950 HU) (%)	28.7 ± 10.2

The mean lung density was reduced and a significant proportion of lung area showed low attenuation, reflecting parenchymal destruction and emphysematous changes.

Table 4: Emphysema Index and Total Lung Volume

Parameter	Mean ± SD
Emphysema Index (%)	30.2 ± 11.5
Total Lung Volume (mL)	5890 ± 820

The emphysema index indicated moderate to severe emphysematous involvement while increased total lung volume suggested hyperinflation.

Table 5: Zonal Distribution of Low Attenuation Areas (%)

Lung Zone	Right Lung (%)	Left Lung (%)
Upper Zone	36.5 ± 9.8	35.2 ± 10.1
Middle Zone	28.1 ± 8.7	27.4 ± 9.0
Lower Zone	21.6 ± 7.5	20.9 ± 7.8

Low attenuation areas were predominantly seen in the upper lung zones compared to middle and lower zones, suggesting an upper lobe predominance of emphysema.

Table 6: Correlation between Key HRCT Parameters

Variables Compared	Correlation (r)	p-value
Emphysema Index vs Mean Lung Density	-0.72	<0.001
Emphysema Index vs Total Lung Volume	0.64	<0.001
Bronchial Wall Thickness vs EI	0.41	0.002
Luminal Diameter vs EI	-0.38	0.004

There was a strong negative correlation between emphysema index and mean lung densityand a positive correlation with total lung volume. Airway changes also showed moderate correlation with emphysema severity.

DISCUSSION

This study was conducted to evaluate the quantitative radiological anatomy of the pulmonary parenchyma in patients with chronic obstructive pulmonary disease (COPD) using HRCT-based morphometric analysis. By focusing on key variables such as airway anatomy, lung density, emphysema index, total lung volume and zonal distribution, this study provides a comprehensive understanding of structural lung changes in COPD.

In this study, bronchial wall thickness was found to be increased while the luminal diameter of bronchi was reduced in COPD patients. These findings reflect airway remodeling which is a well-known pathological feature of COPD. Similar observations were reported by Nakano Y et al., who demonstrated that increased airway wall thickness measured on CT is strongly associated with airflow limitation and disease severity.(Nakano et al., 2000) Patel BD et al.found that airway wall thickening correlates with chronic bronchitis symptoms and contributes significantly to airflow obstruction.(Patel et al., 2008) The moderate correlation observed in our study between bronchial wall thickness and emphysema index further highlights the interplay between airway and parenchymal disease components.

Lung density analysis in our study revealed a reduced mean lung density and a significant proportion of low attenuation areas (LAA < −950 HU). These findings are indicative of emphysematous destruction of lung tissue. Previous studies have validated the use of low attenuation areas as a reliable marker of emphysema. Guenard et al. demonstrated that CT-derived low attenuation areas correlate closely with histopathological evidence of emphysema. (Guenard et al., 1992)Similarly, Dirkje S Postma et al. emphasized that reduced lung density is associated with worsening disease severity and poor clinical outcomes.(Postma et al., 2015) The strong negative correlation between emphysema index and mean lung density observed in this study is in agreement with these findings.

The emphysema index (EI)represents the percentage of lung volume affected by low attenuation areas was significantly elevated in our study population. This indicates moderate to severe emphysematous involvement. Comparable results have been reported by Harvey O Coxson et al., who showed that emphysema index is a sensitive and reproducible measure of disease extent. (Coxson et al., 1999)Furthermore, Meilan K Han et al., in the COPDG gene study highlighted the importance of quantitative CT metrics, including emphysema index, in phenotyping COPD and predicting clinical outcomes. (Han et al., 2011)The positive correlation between emphysema index and total lung volume observed in our study also supports the concept of hyperinflation associated with advanced emphysema.

Total lung volume (TLV) was found to be increased in the majority of patients, indicating hyperinflationwhich is a characteristic feature of COPD. Hyperinflation results from air trapping due to airway obstruction and loss of elastic recoil in emphysematous lungs. These findings are consistent with the work of James C Hogg et al., who described the role of small airway disease and parenchymal destruction in causing airflow limitation and lung hyperinflation. Increased lung volumes have also been associated with reduced exercise capacity and increased dyspnea, further emphasizing their clinical significance.(Hogg et al., 2004)

Zonal distribution analysis in this study revealed that low attenuation areas were more prominent in the upper lung zones compared to middle and lower zones. This pattern is typical of centrilobular emphysema which is commonly associated with smoking. Similar distribution patterns have been reported by John D Newell Jr et al. reported that regional analysis of lung involvement provides valuable insights into disease phenotype and progression.(Newell et al., 2004) The findings of our study further reinforce the importance of regional assessment in COPD.

An important observation in this study was the correlation between different quantitative parameters. The emphysema index showed a strong negative correlation with mean lung density and a positive correlation with total lung volume, which is in line with previous studies. Alejandro A Diaz et al. (2012) also reported similar associations, highlighting the interdependence of structural changes in COPD. Additionally, the moderate correlation between airway parameters and emphysema index suggests that both airway disease and parenchymal destruction contribute to overall disease severity.(Diaz et al., 2012)

The use of HRCT in this study allowed for a non-invasive and detailed evaluation of lung structure. Quantitative analysis reduces observer variability and provides objective measurements that can be used for disease

assessment and monitoring. However, certain limitations should be considered. Variations in patient inspiration during scanning, differences in CT protocols and the cross-sectional nature of the study may affect the accuracy and generalizability of the results. Despite these limitations, the findings are consistent with established literature and support the reliability of HRCT-based morphometric analysis.

CONCLUSION

This study demonstrates that quantitative analysis using high-resolution computed tomography (HRCT) provides a detailed and reliable assessment of structural changes in chronic obstructive pulmonary disease (COPD). Key findings include increased bronchial wall thickness, reduced luminal diameter, decreased mean lung density and increased low attenuation areas, all of which reflect airway remodeling and parenchymal destruction. The emphysema index showed strong correlations with lung density and total lung volume. The predominance of abnormalities in the upper lung zones emphasizes the importance of regional analysis. Overall, combining airway and parenchymal measurements offers a more comprehensive understanding of COPD which can improve diagnosis, disease phenotyping and clinical management.

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