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Quantifying Lung Volume in Patients with Lung Diseases Using Chest CT

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Abstract

Introduction: Lung diseases, such as COPD, pneumonia, and ILD, are significant global health concerns. Accurate lung volume quantification is crucial for effective diagnosis, treatment planning, and disease monitoring. Chest Computed Tomography (CT) offers detailed anatomical and functional insights, acting as a potential biomarker for early detection and prognosis.

Aim: This study aimed to develop and validate a Chest CT-based approach for quantifying lung volume and airway changes in patients with various lung diseases, exploring its utility as a diagnostic and monitoring tool.

Methodology: Conducted over six months at Aster CMI Hospital, Bengaluru, the study included 30 patients. A Philips Ingenuity 128 slices CT scanner was utilized for imaging. Patient data, including demographics, medical history, complaints, and diagnosis, were collected alongside CT scans. The methodology involved analysing existing CT scans and clinical data, assessing patient conditions, employing a standardized CT scan protocol, using semi-automated segmentation via the Philips IntelliSpace Portal system to isolate lungs, and automatically calculating lung volumes.

Results: The study revealed significant variations in lung volume. COPD and ILD patients showed markedly larger lung volumes compared to those with asthma and lower respiratory tract infections. A strong correlation existed between lung volume and disease severity, most evident in COPD and ILD cases (e.g., mild COPD: 2.56L vs. severe: 3.89L; mild ILD: 2.34L vs. severe: 3.21L). Patients with asthma and lower respiratory tract infections generally had smaller lung volumes. The findings highlight lung volume measurement as a valuable biomarker for detecting disease progression and guiding treatment, with higher volumes correlating with increased hospitalization and mortality risks.

Conclusion: This study effectively demonstrates the utility of semi-automated lung segmentation and lung volume measurement in lung disease patients. The results underscore its potential as a crucial biomarker for diagnosis and monitoring. Further research is necessary to fully explore its clinical applications and standardize protocols across diverse lung diseases.

1. Introduction

Lung diseases represent a significant global health burden, affecting millions of people across diverse age groups and geographical regions. They encompass a large spectrum of disorders that impair lung function, compromise respiratory efficiency, often leading to chronic health issues or mortality. Lung diseases, including chronic obstructive pulmonary disease (COPD), pneumonia, and interstitial lung disease (ILD), are some of the leading causes of morbidity and mortality around the world. These conditions arise from different factors, such as smoking, environmental exposures, and genetic factors. Hence, accurate quantification of lung volume is crucial for diagnosis, treatment planning, and monitoring disease progression. The effective diagnosis and management of these underlying conditions depend hugely on advanced medical imaging technologies and accurate diagnostic criteria.

Among these imaging technologies, chest computed tomography (CT) is emerging as a crucial modality, especially in the quantification of lung volume. Quantifying lung volume using chest CT not only provides a detailed anatomical and functional insight for the lungs but it also serves as a potential biomarker for the early detection, monitoring, diagnosis and prognosis of different lung diseases.

Methodology

Our aim was to develop and validate a Chest CT-based approach for quantifying lung volume and airway changes in patients with lung diseases and to investigate its potential as a diagnostic and monitoring tool. A sample size of 30 patients was collected over 6 months at Aster CMI Hospital, Bengaluru, using a Philips Ingenuity 128 slices CT scanner. Patient demographics, medical histories, and diagnostic details were recorded. The methodology involved initial analysis of existing CT scans and clinical data, standardized CT scan protocols, and semi-automated segmentation techniques via Philips IntelliSpace Portal for lung isolation. Lung volumes and airway morphological parameters were calculated and compared between patients and healthy controls, aiming to establish Chest CT as a reliable biomarker for disease diagnosis, severity assessment, and treatment monitoring.

Results

The study revealed significant variations in lung volume among patients with different lung diseases. Patients diagnosed with COPD and ILD exhibited significantly larger lung volumes compared to those with asthma and lower respiratory tract infections. A significant correlation was observed between lung volume and disease severity, with more severe cases demonstrating larger lung volumes. This correlation was particularly pronounced in patients with COPD and ILD. For instance, in COPD patients, the mean lung volume for mild cases was 2.56 liters, while it was 3.89 liters for more severe cases. Similarly, in ILD patients, the mean lung volume was 2.34 liters for mild cases, and 3.21 liters for more severe cases. Table 1 shows the highest and lowest lung volume which was there in our study.

HISTORY	DIAGNOSIS	LUNG VOLUME
H/o of breathlessness and sudden onset of cough from past 4 weeks, patient feels pricking sensation in throat while coughing	Acute pharyngitis with repiratory infections	1016 cc
H/o severe chest pain, pt. also felt chest spasms at night, excessive cough with blood in phlegm. Pt.is an alcohol addict and smokes tobacco.	COPD with stage 4 hypoxia	4100 cc

Table 1 : Highest and lowest lung volume which was there in our study.

Significant differences in lung volume were also observed between different disease groups. Patients with asthma had smaller lung volumes compared to those with COPD and ILD. Patients with lower respiratory tract infections also presented with smaller lung volumes compared to COPD patients.

This study underscores the potential for lung volume measurement to serve as a valuable biomarker for disease diagnosis and monitoring. The application of semi-automated lung segmentation and lung volume measurement can facilitate the early detection of lung disease progression and inform treatment decisions. A detailed analysis of lung volume measurements showed that patients with COPD and ILD had a significant increase in lung volume compared to patients with asthma and lower respiratory tract infections. The reduction in lung volume was more pronounced in patients with mild disease. The study also investigated the relationship between lung volume and patient outcomes, such as hospitalization and mortality. Patients with higher lung volumes were found to have a higher risk of hospitalization and mortality.

Discussion

The observation of significantly larger lung volumes in patients with Chronic Obstructive Pulmonary Disease (COPD) is consistent with well-established pathophysiological understanding(1). COPD is characterized by progressive airflow limitation and often involves emphysema and air trapping, leading to hyperinflation and increased total lung capacity and residual volume(2,3). Quantitative Computed Tomography (CT) has long been recognized as a superior modality for assessing emphysema severity and distribution, which directly contributes to these increased lung volumes . The current study's quantitative results, showing mean lung volumes of 2.56L for mild COPD and 3.89L for severe COPD, numerically reinforce these established concepts, demonstrating the utility of CT-based measurements in objectively differentiating disease severity. Furthermore, the correlation between higher lung volumes and increased risk of hospitalization and mortality in COPD patients aligns with studies showing that severe hyperinflation is associated with worse clinical outcomes and poorer prognosis .

For Interstitial Lung Disease (ILD), the study's finding that "ILD patients showed markedly larger lung volumes compared to those with asthma and lower respiratory tract infections" and that "mean lung volume was 2.34 liters for mild cases, and 3.21 liters for more severe cases" is particularly intriguing. Classical ILD, by definition, is typically a restrictive lung disease characterized by reduced lung volumes (e.g., total lung capacity, forced vital capacity) due to fibrosis and parenchymal stiffening(4). However,

quantitative CT in ILD is known to reveal a spectrum of changes, including ground-glass opacities, reticulation, honeycombing, and traction bronchiectasis. In some specific forms of ILD or at certain stages, complex architectural distortion, or even compensatory airspace enlargement adjacent to areas of dense fibrosis, might contribute to measured lung volumes that are higher than expected in severely fibrotic lungs, or that show an increase with severity *within* a cohort exhibiting complex pathology (5). This finding warrants further investigation to understand the specific ILD subtypes included in this study and the precise CT measurement parameters employed, as it potentially highlights nuanced aspects of lung mechanics in ILD not fully captured by traditional spirometry.

Regarding patients with asthma and lower respiratory tract infections (LRTIs), the study's observation of generally smaller lung volumes is also largely in agreement with clinical expectations. While asthma can lead to transient hyperinflation during acute exacerbations due to air trapping, baseline lung volumes in stable asthma or during remission may not be significantly increased, and can even be reduced in cases of severe, chronic airflow obstruction. In LRTIs, inflammation, consolidation, or pleural effusions can reduce aerated lung volume, leading to decreased overall lung volumes

The application of semi-automated segmentation via the Philips IntelliSpace Portal system represents a significant step forward in making quantitative lung volume measurement more efficient and reproducible. Automated and semi-automated approaches to lung segmentation and volume calculation from CT images have been evolving for decades, demonstrating high accuracy and reduced inter-observer variability compared to manual methods(6). This technological advancement enhances the clinical feasibility of integrating lung volume quantification into routine diagnostic workflows. By streamlining the analysis process, it allows for timely and objective assessment, which is critical for disease diagnosis, monitoring progression, and guiding treatment decisions.

Limitations and Future Directions

While this study effectively demonstrates the utility of semi-automated lung segmentation and lung volume measurement, its relatively small sample size (n=30) warrants caution in generalizing the findings. Future research should involve larger, multi-center cohorts to validate these results across broader patient populations and diverse disease phenotypes. Furthermore, a direct comparison of CT-derived lung volumes with physiological measurements (e.g., spirometry-derived lung volumes, plethysmography) would strengthen the understanding of how these imaging biomarkers correlate with functional impairment(2). Establishing standardized protocols for CT acquisition and post-processing, as also noted by other studies(2,7) (8), is crucial to ensure consistency and comparability of results across different institutions and imaging platforms. Longitudinal studies are also essential to track changes in lung volume over time in response to natural disease progression or therapeutic interventions, thereby solidifying its role as a dynamic biomarker for treatment efficacy and disease modification. Investigating the specific characteristics of the ILD cohort in this study and comparing them with established ILD imaging patterns would also be a valuable avenue for future research.

Conclusion

In conclusion, this study demonstrates the utility of semi-automated lung segmentation and lung volume measurement in patients with lung diseases. The results emphasize the potential of lung volume measurement as a valuable biomarker for disease diagnosis and monitoring. Further studies are needed to explore the full clinical applications of lung volume measurement and to establish standardized protocols for its use across various lung diseases.

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