



A CLINICO-ANATOMICAL EVALUATION OF THORACIC CAGE DIMENSIONS AT MULTIPLE VERTEBRAL LEVELS IN HEALTHY INDIVIDUALS AND PATIENTS WITH CHRONIC OBSTRUCTIVE PULMONARY DISEASE USING COMPUTED TOMOGRAPHY OF THE THORAX

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Abstract

Background: Chronic obstructive pulmonary disease (COPD) is associated with progressive structural alterations of the lungs and thoracic cage due to chronic hyperinflation and parenchymal destruction. These changes modify chest wall geometry, adversely affecting respiratory mechanics. Computed tomography (CT) allows precise assessment of thoracic cage dimensions, yet vertebral-level-wise morphometric evaluation in COPD remains limited.

Methods: This prospective observational study included 90 adult subjects (45 COPD patients and 45 healthy controls) who underwent high-resolution computed tomography (HRCT) of the thorax. Thoracic cage measurements were performed at thoracic vertebral levels T3–T12, including maximum transverse diameter and minimum anteroposterior diameter. Haller's Index (HI) was calculated at each level. COPD patients were further categorized into emphysema-predominant and chronic bronchitis–predominant phenotypes and staged according to GOLD criteria. Morphometric parameters were compared between groups and correlated with disease phenotype and severity.

Results: Emphysema-predominant COPD was the most common phenotype (57.8%). Compared to chronic bronchitis–predominant patients, emphysema patients demonstrated significantly higher mean transverse diameter (271.8 ± 22.3 mm vs 254.6 ± 18.9 mm), reduced anteroposterior diameter (75.9 ± 7.1 mm vs 82.4 ± 7.6 mm), and elevated Haller's Index (3.52 ± 0.39 vs 3.09 ± 0.28 ; $p < 0.001$). Haller's Index showed significant positive correlations with bronchial wall thickness and chronic bronchitis severity. Progressive increases in transverse diameter and HI were observed with advancing GOLD stage. Vertebral-level analysis revealed a gradual increase in HI from upper to lower thoracic levels.

Conclusion: Vertebral-level-wise CT assessment demonstrates significant thoracic cage remodeling in COPD, particularly in emphysema-predominant disease, and correlates with disease severity. Haller's Index serves as a useful quantitative marker of thoracic structural alteration in COPD.

Keywords: COPD, Haller's Index, CT, GOLD stage.

INTRODUCTION

Chronic obstructive pulmonary disease (COPD) is a common, progressive respiratory disorder characterized by persistent airflow limitation and structural alterations of the lungs and chest wall [1]. Chronic lung hyperinflation and parenchymal destruction in COPD lead to remodeling of the thoracic cage, resulting in increased transverse diameter, reduced anteroposterior depth, and the classical barrel-shaped chest configuration, which adversely affects respiratory mechanics and functional capacity [2,3].

Computed tomography (CT) of the thorax provides a precise and reproducible method for evaluating thoracic cage morphology, allowing accurate assessment of osseous structures and lung parenchyma simultaneously [4]. While several CT-based studies have described thoracic changes in COPD, most have relied on single-level measurements or focused primarily on pulmonary findings, with limited emphasis on vertebral-level-wise thoracic cage dimensions [5,6].

A clinico-anatomical evaluation of thoracic cage dimensions at multiple vertebral levels may provide a more comprehensive understanding of regional thoracic remodeling in COPD. Therefore, the present study aims to compare thoracic cage dimensions and Haller's Index at multiple thoracic vertebral levels in healthy individuals and patients with COPD using computed tomography of the thorax, and to correlate these findings with disease phenotype and severity.

MATERIALS AND METHODS

Study Design and Setting

This prospective observational study was conducted in the Department of Anatomy at a tertiary care hospital in Indore between May 2020 and December 2025, including a dedicated period for data analysis. Ethical approval was obtained from the Institutional Ethics Committee prior to study initiation.

Study Population

Adult subjects undergoing HRCT thorax imaging were enrolled and categorized into two groups: normal individuals (control group) and patients with chronic obstructive pulmonary disease (COPD). Both male and female participants were included.

Inclusion Criteria

Control Group

- Adults aged 18–70 years
- Normal HRCT thorax with no evidence of pulmonary disease
- No history of chronic respiratory illness

COPD Group

- Adults aged 40–70 years
- Clinically diagnosed and stable COPD cases as per GOLD guidelines
- HRCT thorax showing features of COPD
- Available spirometric confirmation of airflow limitation

Exclusion Criteria

- Bronchial asthma, interstitial lung disease, pulmonary tuberculosis, or lung malignancy
- Congenital or acquired chest wall deformities
- Previous thoracic surgery or major chest trauma
- Significant pleural disease
- Poor-quality or incomplete HRCT images
- Acute COPD exacerbation at the time of imaging

Sample Size

Sample size was calculated using the formula for comparison of two means:

Formula

$$n = 2 (Z\alpha + Z\beta)^2 \sigma^2 / d^2$$

Calculation

$$n = 2 (1.96 + 0.84)^2 \times (5)^2 / (3)^2$$

$$n = 2 (2.8)^2 \times 25 / 9$$

$$n = 2 \times 7.84 \times 25 / 9$$

$$n = 392 / 9$$

$$n = 43.5 \approx 44 \text{ subjects per group}$$

Assuming an expected mean difference of 3 cm and a pooled standard deviation of 5 cm, with 95% confidence and 80% power, the required sample size was **44 subjects per group**.

HRCT Thorax Protocol

HRCT thorax was performed using a standardized protocol with subjects in the supine position during full end-inspiration breath-hold. Thin-section axial images were acquired covering the entire thoracic cage. Only good-quality images with adequate inspiration and complete visualization from T3 to T12 vertebral levels were included.

Images were reconstructed at a slice thickness of 1.5 mm using a high-spatial-frequency algorithm and analyzed on the institutional PACS in the bone window.

Group Allocation

- **Group I (Control):** Normal HRCT thorax with no radiological evidence of COPD
- **Group II (COPD):** HRCT-confirmed COPD based on established radiological criteria

Identification of Vertebral Levels

Thoracic vertebral levels T3–T12 were identified using sagittal reconstructions, supplemented by anterior anatomical landmarks and standard axial CT reference criteria to ensure accuracy and reproducibility.

Thoracic Cage Measurements

Measurements were performed on axial images at each vertebral level using PACS tools:

- **Maximum transverse diameter:** Greatest internal distance between inner rib margins
- **Minimum anteroposterior diameter:** Shortest distance between posterior sternum (or linea alba below T10) and anterior vertebral body

All measurements were taken perpendicular to anatomical axes.

Haller's Index

Haller's Index (HI) was calculated at each vertebral level (T3–T12) as:

Haller's Index (HI) = Maximum Transverse Diameter / Minimum Anteroposterior Diameter

This vertebral-level-wise approach allowed detailed assessment of regional thoracic cage morphology.

HRCT-Based Diagnosis of COPD

COPD diagnosis was based on HRCT findings, including emphysema and/or chronic bronchitis.

- **Emphysema:** Areas of low attenuation without visible walls, vascular pruning, air trapping, and presence of bullae
- **Chronic bronchitis:** Bronchial wall thickening ($>1.28 \pm 0.11$ mm), luminal narrowing, and increased bronchovascular markings

Emphysema was classified as mild, moderate, or severe based on the extent of low-attenuation areas.

GOLD Staging

COPD severity was classified according to GOLD criteria using post-bronchodilator spirometry (FEV₁ % predicted). Thoracic morphometric parameters were correlated with GOLD stages and COPD phenotypes (emphysema-predominant and chronic bronchitis-predominant).

Observer Reliability

All measurements were performed by a single trained observer following a standardized protocol to minimize inter-observer variability.

Statistical Analysis

Data were analyzed using appropriate statistical software. Continuous variables were expressed as mean $\pm$ standard deviation. Comparisons between groups were performed using Student's *t*-test or Mann-Whitney *U* test as appropriate. A *p*-value < 0.05 was considered statistically significant.

Result

The present prospective observational study evaluated thoracic cage morphometry using high-resolution computed tomography (HRCT) in 90 adult subjects from Central India. The study population comprised 45 normal subjects (Control group) and 45 patients with HRCT-confirmed chronic obstructive pulmonary disease (COPD group). Thoracic dimensions and Haller's Index were analysed vertebral-level-wise from T3 to T12.

A total of 90 subjects were included in the study, comprising 45 patients with chronic obstructive pulmonary disease (COPD) and 45 healthy controls. Within the COPD cohort, emphysema-predominant disease was the most common phenotype (57.8%), followed by chronic bronchitis-predominant disease (24.4%), while 17.8% of patients showed mixed emphysema and chronic bronchitis features.

Comparison between emphysema-predominant and chronic bronchitis-predominant COPD patients showed no significant difference in mean age (59.3 ± 8.1 years vs 56.2 ± 7.4 years; $p = 0.214$), with male predominance in both groups. The mean maximum transverse thoracic diameter was significantly greater in emphysema patients compared to those with chronic bronchitis (271.8 ± 22.3 mm vs 254.6 ± 18.9 mm; $p = 0.018$). Conversely, the mean anteroposterior diameter was significantly reduced in emphysema-predominant COPD (75.9 ± 7.1 mm) compared to chronic bronchitis-predominant COPD (82.4 ± 7.6 mm; $p = 0.021$). Consequently, emphysema patients demonstrated a significantly higher mean Haller's Index (3.52 ± 0.39) than chronic bronchitis patients (3.09 ± 0.28 ; $p < 0.001$). A barrel chest configuration was more frequently observed in emphysema-predominant patients (65.4%) than in those with chronic bronchitis (36.4%).

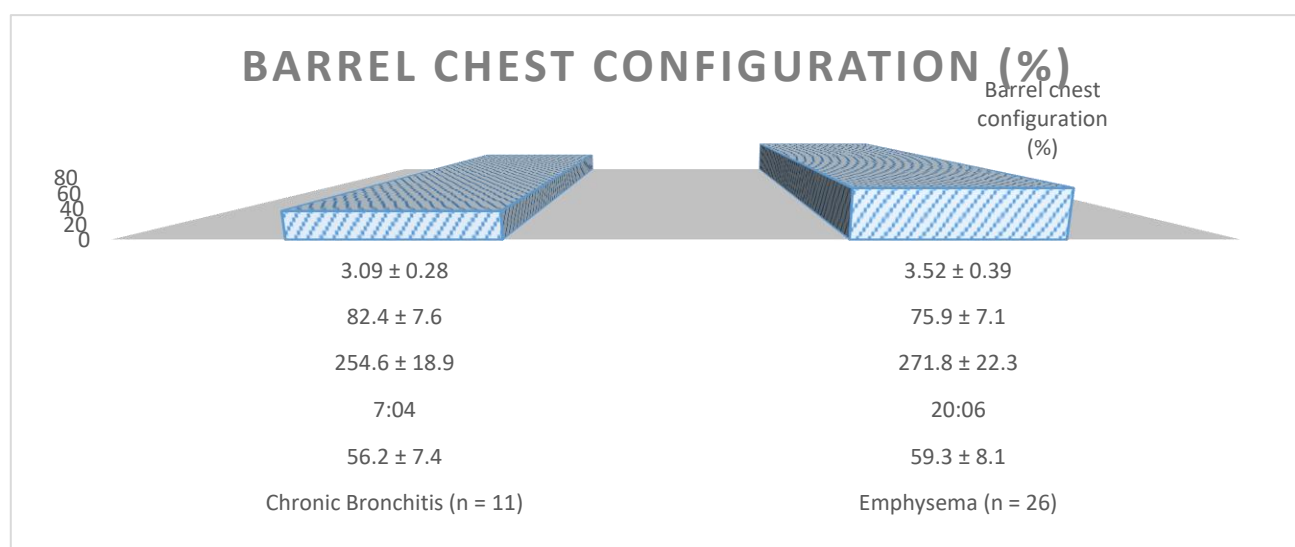
Correlation analysis in chronic bronchitis-predominant COPD patients revealed a moderate positive relationship between bronchial wall thickness and Haller's Index ($r = 0.46$, $p = 0.028$). Similarly, the extent of airway involvement showed a significant positive correlation with Haller's Index ($r = 0.41$, $p = 0.036$). The chronic bronchitis severity score also demonstrated a significant positive correlation with Haller's Index ($r = 0.49$, $p = 0.019$), indicating increasing thoracic cage alteration with greater airway disease severity.

Stage-wise analysis according to GOLD classification demonstrated a progressive increase in maximum transverse thoracic diameter and Haller's Index with advancing disease severity in both COPD phenotypes. Emphysema-predominant patients consistently exhibited higher transverse diameters and Haller's Index values and lower anteroposterior diameters across all GOLD stages compared to chronic bronchitis-predominant patients. The highest Haller's Index values were observed in emphysema-predominant patients with GOLD Stage IV disease (3.80 ± 0.25), reflecting advanced thoracic cage remodeling.

Vertebral-level-wise analysis of Haller's Index in the COPD group showed a gradual increase from the upper to the lower thoracic levels. Mean Haller's Index values increased from 2.93 ± 0.34 at T3 to 3.68 ± 0.45 at T12, indicating progressive transverse expansion and relative anteroposterior flattening of the thoracic cage toward the lower thoracic segments.

Table 1: Comparison between Chronic Bronchitis and Emphysema in COPD Patients (HRCT-Based)

Parameter	Chronic Bronchitis (n = 11)	Emphysema (n = 26)	p-value
Mean age (years) $\pm$ SD	56.2 $\pm$ 7.4	59.3 $\pm$ 8.1	0.214
Male : Female ratio	7 : 4	20 : 6	—
Mean maximum transverse diameter (mm) $\pm$ SD	254.6 $\pm$ 18.9	271.8 $\pm$ 22.3	0.018*
Mean anteroposterior diameter (mm) $\pm$ SD	82.4 $\pm$ 7.6	75.9 $\pm$ 7.1	0.021*
Mean Haller's Index $\pm$ SD	3.09 $\pm$ 0.28	3.52 $\pm$ 0.39	< 0.001*
Barrel chest configuration (%)	36.4	65.4	—



.Figure - Comparison between Chronic Bronchitis and Emphysema in COPD Patients (HRCT-Based)

Table 2: Correlation of Chronic Bronchitis with Haller's Index in COPD Patients

Parameter	Correlation Coefficient (r)	p-value
Bronchial wall thickness vs Haller's Index	+0.46	0.028*
Extent of airway involvement vs Haller's Index	+0.41	0.036*
Chronic bronchitis severity score vs Haller's Index	+0.49	0.019*

Table 3 Relationship between Emphysema and Chronic Bronchitis in COPD Patients (HRCT-Based)

COPD Phenotype	Number of Subjects (n)	Percentage (%)
Predominant Emphysema only	26	57.8
Predominant Chronic Bronchitis only	11	24.4
Mixed Emphysema + Chronic Bronchitis	8	17.8
Total COPD patients	45	100

Table 4 -Thoracic Cage Dimensions and Haller's Index According to GOLD Stage in Emphysema-Predominant and Chronic Bronchitis-Predominant COPD Patients (n = 45)

GOLD Stage	Phenotype	n	Maximum Transverse	Minimum Anteroposterior	Haller's Index Mean $\pm$ SD
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			Diameter (mm) Mean $\pm$ SD	Diameter (mm) Mean $\pm$ SD	
Stage I (Mild)	Emphysema	3	260.5 $\pm$ 10.8	81.2 $\pm$ 4.9	3.05 $\pm$ 0.15
	Chronic Bronchitis	3	245.8 $\pm$ 8.2	86.4 $\pm$ 5.1	2.88 $\pm$ 0.12
Stage II (Moderate)	Emphysema	10	272.1 $\pm$ 13.5	77.4 $\pm$ 6.1	3.30 $\pm$ 0.19
	Chronic Bronchitis	5	255.7 $\pm$ 12.3	82.8 $\pm$ 5.6	3.05 $\pm$ 0.16
Stage III (Severe)	Emphysema	9	281.3 $\pm$ 15.8	74.1 $\pm$ 6.4	3.58 $\pm$ 0.22
	Chronic Bronchitis	5	268.2 $\pm$ 14.7	78.5 $\pm$ 5.9	3.28 $\pm$ 0.18
Stage IV (Very Severe)	Emphysema	4	290.2 $\pm$ 16.7	71.3 $\pm$ 6.0	3.80 $\pm$ 0.25
	Chronic Bronchitis	3	278.1 $\pm$ 15.2	74.9 $\pm$ 5.7	3.55 $\pm$ 0.21

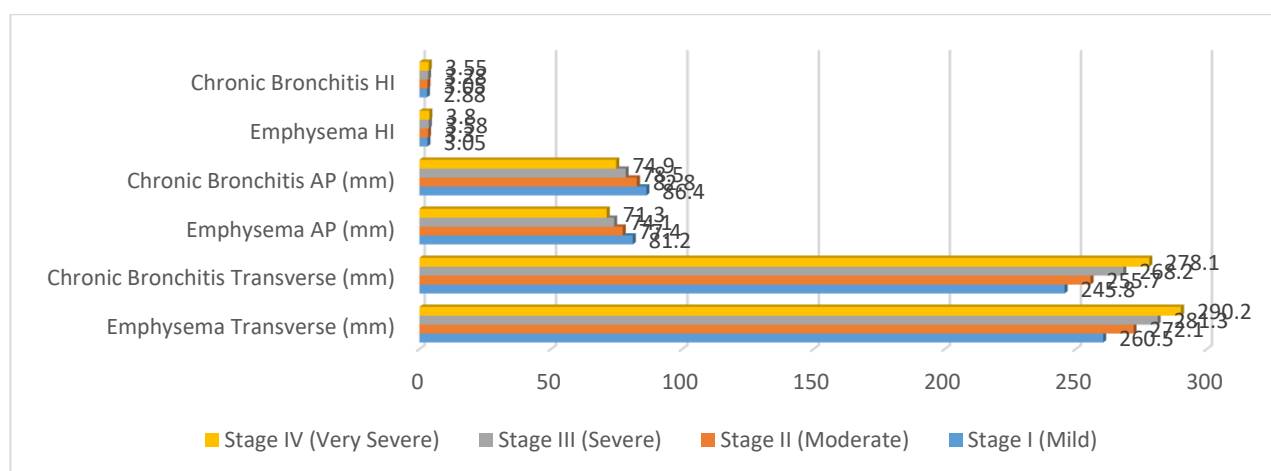


Figure 2- Thoracic Cage Dimensions and Haller's Index According to GOLD Stage in Emphysema-Predominant and Chronic Bronchitis-Predominant COPD Patients (n = 45)

Table 5: Vertebral-Level-Wise Haller's Index in COPD Group

Vertebral Level	Mean HI $\pm$ SD
T3	2.93 $\pm$ 0.34
T5	3.16 $\pm$ 0.37
T7	3.34 $\pm$ 0.40
T9	3.52 $\pm$ 0.42
T12	3.68 $\pm$ 0.45

DISCUSSION

The present prospective observational study evaluated thoracic cage morphometry in COPD patients using HRCT and demonstrated significant alterations in thoracic dimensions and Haller's Index (HI), particularly in emphysema-predominant disease. Vertebral-level-wise assessment from T3 to T12 revealed progressive transverse expansion and anteroposterior flattening of the thoracic cage, reflecting structural remodeling secondary to chronic lung hyperinflation.

In the current study, emphysema-predominant COPD patients showed significantly higher maximum transverse diameters and Haller's Index values, along with reduced anteroposterior diameters, compared to chronic bronchitis-predominant patients. These findings are consistent with the classical

description of a “barrel-shaped” thorax in emphysema due to chronic air trapping and loss of elastic recoil, as described by Thurlbeck (1976) [7] and later confirmed by CT-based studies.

Madani et al. (2006) [8] reported that emphysema severity on HRCT is associated with increased thoracic transverse dimensions and flattening of the diaphragm, findings that parallel the significantly higher HI observed in emphysema patients in the present study (3.52 ± 0.39). Similarly, Sverzellati et al. (2009) [9] demonstrated that emphysema-dominant COPD patients exhibit greater chest wall expansion than those with airway-predominant disease, supporting the observed inter-phenotypic differences in thoracic morphology.

In contrast, chronic bronchitis–predominant patients in the present study showed relatively preserved anteroposterior diameter and lower HI values, indicating less pronounced chest wall remodeling. This observation aligns with the work of Lynch et al. (2000) [10], who emphasized that airway-predominant COPD primarily affects bronchial structures with comparatively limited impact on global thoracic cage geometry.

A moderate positive correlation was observed between bronchial wall thickness and Haller’s Index in chronic bronchitis patients. This suggests that airway remodeling may contribute indirectly to thoracic configuration changes, possibly through altered ventilatory mechanics and increased work of breathing. Similar associations between airway wall thickening and thoracic structural adaptation have been reported by Nakano et al. (2000) [11], who demonstrated CT-based correlations between airway dimensions and lung hyperinflation parameters.

The present study demonstrated a progressive increase in transverse thoracic diameter and Haller’s Index with advancing GOLD stage, particularly in emphysema-predominant patients. This trend supports the concept that thoracic cage remodeling is a dynamic process that parallels disease severity. Washko et al. (2011) [12] reported that worsening airflow limitation is associated with increased lung volumes and chest wall expansion on CT, findings that corroborate the stage-wise increase in HI observed in the present study.

Emphysema-predominant patients in GOLD Stage IV exhibited the highest HI values, reflecting advanced hyperinflation and fixed thoracic expansion. Similar observations were reported by Coxson et al. (2004) [13], who demonstrated that severe emphysema results in irreversible structural changes of the thoracic cage.

A key strength of the present study is the vertebral-level–wise analysis of Haller’s Index from T3 to T12, which revealed a gradual increase in HI toward the lower thoracic levels. This segmental variation likely reflects regional differences in rib orientation and diaphragmatic mechanics. Aquino et al. (2001) [14] highlighted the importance of standardized vertebral landmarks in CT-based thoracic measurements, supporting the methodological approach used in this study.

Most previous studies have relied on single-level measurements, typically at the level of maximal deformity. The multi-level approach adopted in the present study provides a more comprehensive assessment of thoracic cage morphology and allows detection of subtle regional changes associated with COPD progression.

The observed increase in Haller’s Index with emphysema severity suggests that HI may serve as a simple and reproducible radiological marker of thoracic remodeling in COPD. Incorporating vertebral-level–wise HI assessment into routine HRCT evaluation may aid in phenotypic characterization, disease severity assessment, and longitudinal monitoring of structural progression in COPD patients.

Conclusion

The present study demonstrates significant thoracic cage remodeling in COPD, particularly in emphysema-predominant disease, characterized by increased transverse diameter, reduced anteroposterior diameter, and elevated Haller’s Index. These changes showed a progressive increase with advancing GOLD stage and from upper to lower thoracic vertebral levels. Vertebral-level–wise CT-based assessment of Haller’s Index provides a reliable marker for evaluating structural thoracic alterations associated with COPD severity.

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