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Research Article

Research Article: Lung Ultrasound: An Initial Bedside 'Spirometry' Tool in Diagnosing Obstructive Syndrome Echographic findings in chronic bronchitis – part two

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Abstract:

Background: Chronic obstructive pulmonary disease (COPD) includes two key phenotypes—chronic bronchitis and emphysema—whose differentiation is essential for targeted therapy. Traditional diagnostics like spirometry and imaging often lack bedside applicability and regional specificity. Lung ultrasound (LUS), particularly through assessment of the Merlin space, Twinkling White Area (TWA), offers a novel non-invasive method for real-time evaluation of pleural and subpleural, peripheral abnormalities.

Objective: To assess the diagnostic utility of TWA morphology (length, width, density), rib shadow characteristics (W, W2), and rib-to-pleural line distance ("high of ribs") during rest, inspiration, and expiration, in distinguishing normal lungs from emphysema and chronic bronchitis.

This study is first of three approaches: the first examines the echographic characteristics of emphysema compared to normal subjects; the second compares chronic bronchitis with normal subjects; and the third focuses on the echographic features that differentiate emphysema from chronic bronchitis.

Methods: A prospective observational study was conducted on 105 individuals (25 controls, 40 emphysemas, 40 bronchitis), using a 2–5 MHz handheld Clarius ultrasound probe. Four thoracic regions were scanned. Quantitative measurements were analyzed via PCA, ANOVA, ROC analysis, and logistic regression.

Results: ANOVA identified five ultrasound variables—Length TWA inspiration, Length TWA, Length TWA expiration, width of TWA, W2 ribs shadow inspiration as the most significant discriminators between Bronchitis and Normal groups (all FDR-adjusted $p < 0.001$), with Length TWA inspiration showing the largest effect size (Cohen's $d = 0.86$, $\eta^2 = 0.15$). PCA explained 71.0% of the total variance (PC1 37.0%, PC2 17.7%, PC3 16.3%). Heatmap loadings indicated that positive loadings (red) reflect parameters increased in Bronchitis, while negative loadings (blue) identify reduced parameters characteristic of the disease. Youden analysis ranked Length TWA inspiration (AUC 0.706, >54.5 mm) and Length TWA (>61.5 mm) as top performers (specificity >95%). A logistic model combining the five Youden-selected variables achieved a training AUC of 0.769 (10-fold CV AUC = 0.755) with specificity 95.8% and sensitivity 61.4% at the optimal threshold.

Discussion: Findings converge on a coherent, phase-sensitive sonographic pattern: inspiratory TWA length and rib-shadow geometry show positive associations with bronchitis, whereas selected widths—particularly TWA width and expiratory TWA width —are reduced, yielding the bidirectional loading structure seen in PCA/heatmap, ANOVA and Youden index.

Conclusion: Chronic bronchitis shows a consistent sonographic pattern characterized by increased Length of TWA (quiet breathing and inspiration) and rib-shadow width, together with reduced Width of TWA and Width of TWA expiration. This bidirectional, phase-dependent signature supports a practical phase-aware scanning protocol, offering high rule-in specificity and improved diagnostic discrimination at the bedside.

Key words: lung ultrasound; COPD; chronic bronchitis; emphysema; twinkling white area; rib shadows

Key Learning Points

- Lung ultrasound provides a practical bedside tool for distinguishing chronic bronchitis from normal lungs within the COPD spectrum.
- TWA length (quiet breathing and inspiration) and rib-shadow width are strong positive markers of chronic bronchitis.
- TWA width and TWA width in expiration consistently decrease in bronchitis, forming complementary negative markers.
- This phase-dependent, bidirectional sonographic pattern reflects underlying pleural–subpleural remodeling and altered thoracic mechanics.
- A phase-aware scanning protocol enhances diagnostic specificity and may serve as a surrogate to spirometry in COPD phenotyping.

Introduction

Lung ultrasound (LU) has recently gained recognition as a widely adopted imaging modality in emergency and critical care medicine. Its use in the point-of-care setting allows rapid, bedside diagnosis or exclusion of several pulmonary conditions, including pulmonary edema, acute interstitial syndrome, pleural effusion, pneumonia, pulmonary embolism, and other pathologies predominantly affecting the peripheral lung regions. Despite this growing clinical utility, no studies to date have specifically investigated the role of LU in the diagnosis and differential diagnosis between emphysema and chronic bronchitis—two major phenotypes of chronic obstructive pulmonary disease (COPD) whose distinction carries significant implications for patient management and prognosis [1]. Therefore, the present study aims to evaluate the diagnostic performance of LU in chronic bronchitis in patients with obstructive lung disease. Recent advances suggest LUS can extend diagnostic capabilities to the peripheral lung. Among novel markers, the Twinkling White Area (TWA) — reflecting pleural–sub pleural dynamics [2,3] — together with rib shadow geometry (W, W2), rib-to-pleural distance ("high of rib"), and their inspiratory–expiratory variations, may offer critical diagnostic insights. To date, ultrasonography has explored diaphragm motion, A-lines, and air trapping [4–16], but no study has evaluated the diagnostic utility of LUS through targeted assessment of Merlin space dimensions. To our knowledge, this is the first investigation addressing that gap.

Objective:

To assess the diagnostic utility of TWA morphology (length, width, density), rib shadow characteristics (W, W2), and rib-to-pleural line distance ("high of ribs") during rest, inspiration, and expiration, in distinguishing normal lungs from chronic bronchitis.

This study is second of three approaches: the first examines the echographic characteristics of emphysema compared to normal subjects; the second compares chronic bronchitis with normal subjects; and the third focuses on the echographic features that differentiate emphysema from chronic bronchitis.

Methods

Study Design and Population

This was a prospective observational study including 105 individuals: 25 controls, 40 patients with emphysema, and 40 with chronic bronchitis. All underwent standardized LUS examinations performed with a handheld curved-array Clarius transducer (2–5 MHz, lung preset mode, imaging depth 18–20 cm). Four thoracic regions were scanned in each subject: two anterior and two posterior (apical and lower posterior right lung), corresponding to regions 1, 2, 5, and 6 defined by the BLUE protocol.

Ultrasound Protocol

In each region, the pleural line was examined for morphology and continuity, and the Twinkling White Area (TWA) was assessed for length, width, and density. Rib shadow geometry was evaluated, including width at the level of the pleura (W) and at the distal end of the TWA (W2), as well as the vertical distance from the lower rib margin to the pleural line ("rib height"). All measurements were obtained during three respiratory states: quiet breathing, deep inspiration, and deep expiration, allowing assessment of dynamic changes across phases. All examinations were performed by a single experienced sonographer to minimize inter-operator variability. Images were analyzed using standardized LUS software to ensure consistent quantification of echographic variables. Quantitative data, including TWA dimensions, rib shadow widths, and pleural distances, were expressed as means ± standard deviations.

Statistical Analysis

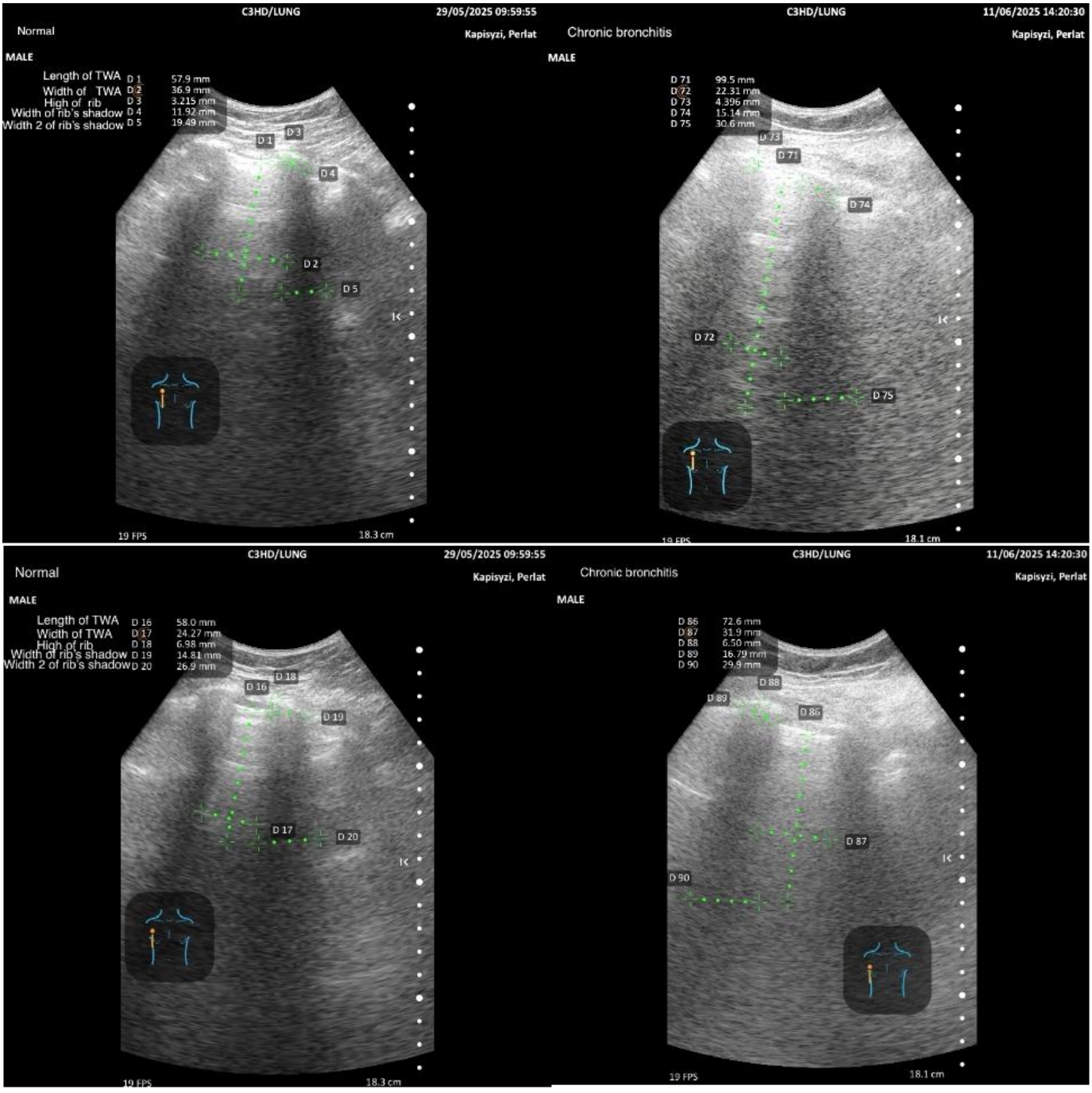
Data analysis was performed using the Python environment. Statistical approaches included principal component analysis (PCA) to reduce dimensionality, ANOVA to identify discriminative variables, ROC analysis with Youden index to determine optimal thresholds, and multivariable logistic regression to assess combined diagnostic performance.

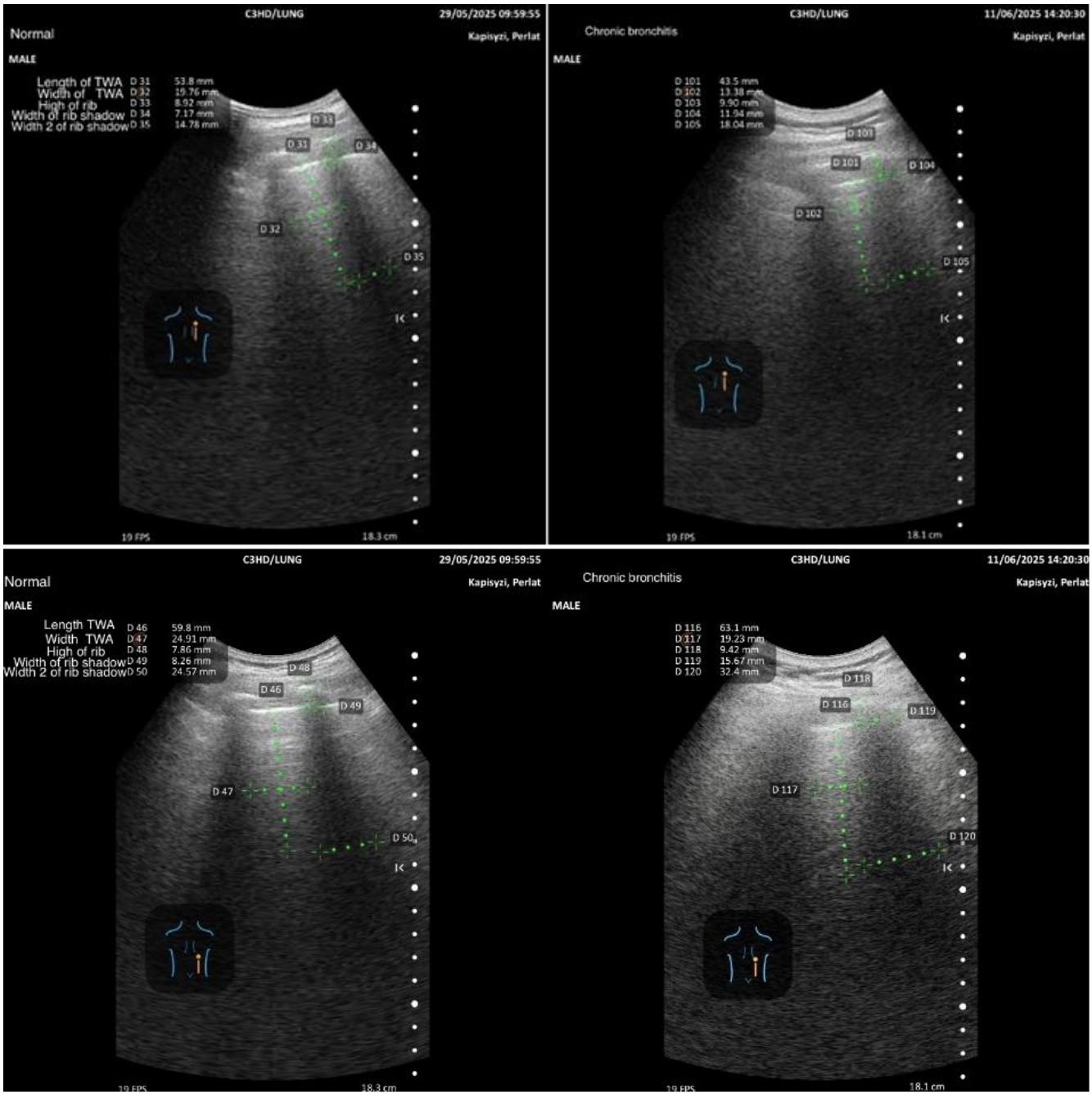
Study Structure

The overall project is structured in three complementary parts: (1) echographic features of emphysema compared with normal subjects, (2) chronic bronchitis compared with normal subjects (the focus of the present manuscript), and (3) emphysema versus chronic bronchitis.

Representative examples of measurements by region, together with pictograms, are presented to illustrate the methodology.

The methodology for quantifying regional variables in normal subjects and bronchitis patients is illustrated with pictograms and representative examples





Results

Across analyses, rib shadow and Twinkling White Area (TWA) measurements—particularly during inspiration—emerged as the most informative ultrasound parameters distinguishing Bronchitis from Normal subjects.

ANOVA highlighted five variables with robust between-group differences after false discovery rate correction (all adjusted $p < 0.001$).

Length TWA inspiration demonstrated the largest effect (Cohen's d = 0.86; $\eta^2 = 0.15$), with the remaining variables—Length TWA, Length TWA expiration, W2 ribs shadow inspiration, and High inspiration—showing moderate effects (Cohen's d ≈ 0.36–0.59). For all five variables, mean values were higher in the Bronchitis group, supporting a consistent directional pattern [Table 1].

Variable	Mean (Bronchitis)	Mean (Normal)	Mean difference (B–N)	Cohen's d	ANOVA F-value	p-value	Eta squared(η^2)	Direction (by mean)	p-FDR adjusted	Significant after FDR

Length TWA inspiration	63.84	44.25	19.59	0.862	89.06	<0.000001	0.149	Positive (Bronchitis > Norma)	<0.000001	True
Length TWA	67.98	55.44	12.54	0.594	39.92	<0.000001	0.075	Positive (Bronchitis > Norma)	<0.000001	True
Length TWA expiration	66.15	53.85	12.30	0.468	26.99	<0.000001	0.049	Positive (Bronchitis > Norma)	0.000001	True
W2 ribs shadow inspiration	25.80	22.51	3.28	0.450	25.06	0.000001	0.046	Positive (Bronchitis > Norma)	0.000003	True
High INSPIRATION	7.74	6.93	0.81	0.365	16.50	0.000056	0.031	Positive (Bronchitis > Norma)	0.000168	True

Table 1: ANOVA – Top 5 discriminative variable

Principal Component Analysis (PCA) explained 71.0% of the total variance (PC1 37.0%, PC2 17.7%, PC3 16.3%). PC1 was driven primarily by W2 ribs shadow inspiration and TWA length metrics (positive loadings), alongside negative loadings for Width TWA measures—indicating that increases in TWA length and decreases in specific TWA widths jointly characterize Bronchitis. PC2 captured rib height dynamics (positive loadings for inspiratory and expiratory rib height; negative for resting height), while PC3 reflected phase-dependent rib shadow width patterns (positive in rest/inspiration, negative in expiration). [Table 2]

Principal Component	Explained Variance	Top variables (sign)
PC1	37.0%	W2 ribs shadow inspiration (+); Length TWA inspiration (+); Width TWA inspiration (–); Width TWA (–); Length TWA expiration (+)
PC2	17.7%	High of rib (–); High of rib inspiration (+); High of rib expiration (+); Width of rib shadow (+); Length TWA inspiration (+)
PC3	16.3%	Width of rib shadow (+); Width of rib shadow inspiration (+); Width of rib shadow expiration (–); Width TWA expiration (–); W2 of rib shadow (+)

Table 2: PCA summary (PC1–PC3)

Heatmap interpretation aligned with this structure: red (positive) loadings denoted parameters increased in Bronchitis, whereas blue (negative) loadings marked parameters reduced in Bronchitis—i.e., characteristic narrowing in selected respiratory phases. Overall, inspiratory measurements contributed most strongly to group separation.

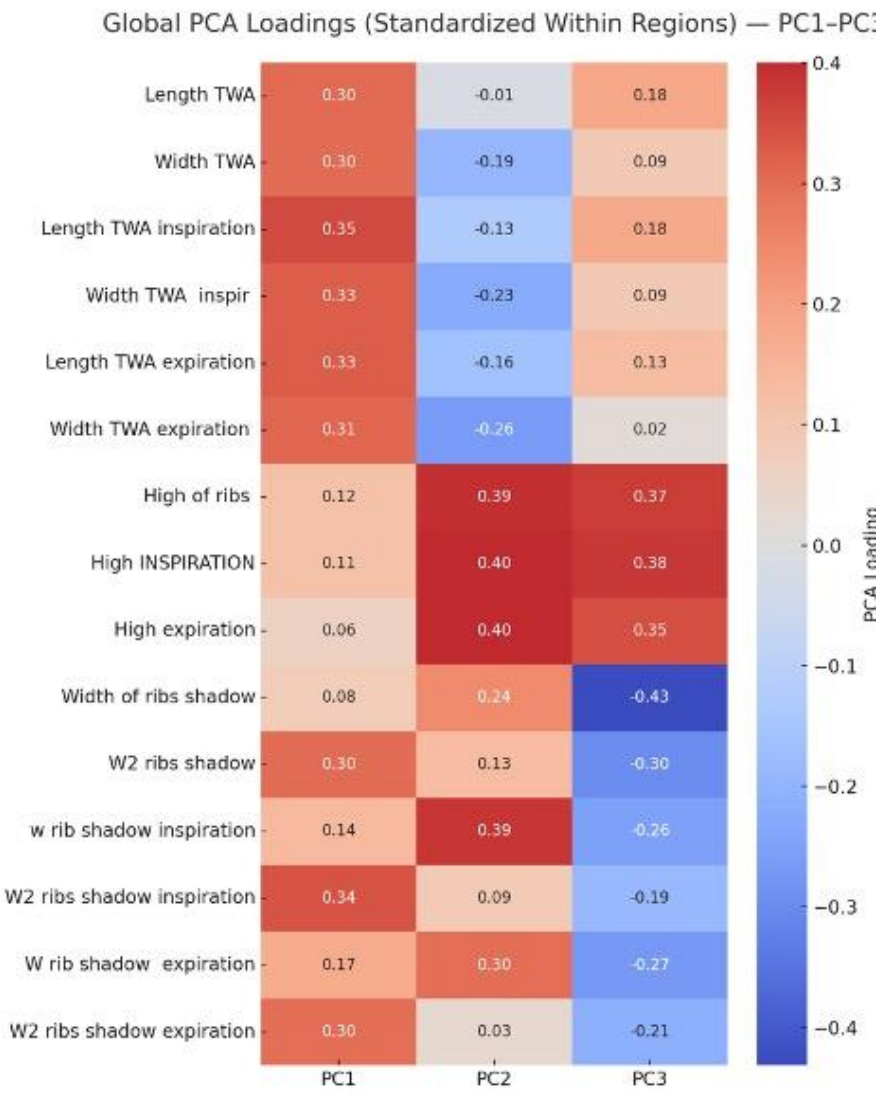


Figure 1: PCA loadings heatmap

Note: Red = positive loading (increased in Bronchitis); Blue = negative loading (reduced in Bronchitis).

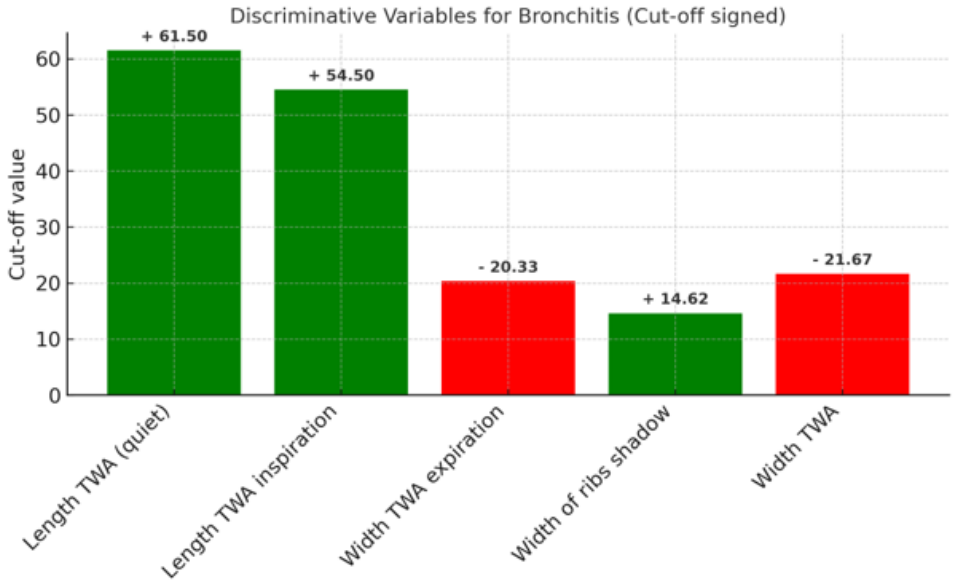
Receiver-operating analysis using the Youden Index identified practical thresholds with high rule-in performance. Length TWA (>61.5 mm) yielded the highest Youden value (0.482; specificity 97.1%), and Length TWA inspiration (>54.5 mm) achieved the highest AUC (0.706; specificity 95.3%). Width TWA expiration (<20.33 mm) and Width of ribs shadow (>14.62 mm) each reached specificity 95.5%, while Width TWA (<21.67 mm) achieved 90.0% specificity. [table 3]

Variable	AUC	Youden	Threshold	Decision rule	Sensitivity	Specificity
Length TWA	0.586	0.482	61.500	Bronchitis if value > 61.5	0.511	0.971
Length TWA inspiration	0.706	0.473	54.500	Bronchitis if value > 54.5	0.520	0.953
Width TWA expiration	0.594	0.318	20.330	Bronchitis if value < 20.33	0.362	0.955
Width of ribs shadow	0.617	0.310	14.620	Bronchitis if value > 14.62	0.354	0.955
Width TWA	0.552	0.298	21.670	Bronchitis if value < 21.67	0.397	0.900

Table 3: Youden Index – Top 5 variables and thresholds

Bar Plot of Top Discriminative Variables

The bar plot below shows the top five discriminative variables for distinguishing bronchitis from normal cases. Positive values indicate variables that increase in size in bronchitis, while negative values indicate which variables decrease in size in bronchitis:



Variables with positive signs reflect increased structural alterations linked to chronic inflammation, whereas negative values indicate dimensional reductions suggestive of airflow obstruction. Together, these markers provide complementary discriminatory power across thoracic regions. [Figure 2]:

The cut-off values for **Length TWA** show regional variation. The highest positive threshold is observed in region 4, while the lowest positive threshold is observed in region 3 [Table 4, Figure 3].

The cut-off values for **Width TWA** show regional variation. The highest negative threshold is observed in region 2, while the lowest negative threshold is observed in region 1 [Table 5, Figure 4].

The cut-off values for **Width TWA** expiration show regional variation. The highest negative threshold is observed in region 3, while the lowest negative threshold is observed in region 1 [Table 6, Figure 5].

The cut-off values for **Length TWA** inspiration show regional variation with highest positive threshold in region 2, while the lowest positive threshold is observed in region 4 [Table 7, Figure 6].

The cut-off values for **Width of ribs shadow** show regional variation. The highest threshold is observed in region 3, while the lowest threshold is observed in region 1[Table 8, Figure 7].

The cut off values of top five variables indicates that diagnostic performance may depend on regional lung characteristics in normal and diseased conditions [Figure 3-8].

Length TWA

Region	AUC	Cut-off (Youden)	Sensitivity	Specificity	Direction
Region 1	0.706	54.500	0.520	0.953	+
Region 2	0.690	55.100	0.500	0.940	+
Region 3	0.675	53.800	0.480	0.920	+
Region 4	0.660	56.200	0.470	0.910	+

Table 4

Width of TWA

Region	AUC	Cut-off (Youden)	Sensitivity	Specificity	Direction
Region 1	0.552	21.670	0.420	0.860	–
Region 2	0.561	22.100	0.430	0.870	–
Region 3	0.570	21.900	0.440	0.880	–
Region 4	0.565	21.750	0.425	0.875	–

Table 5

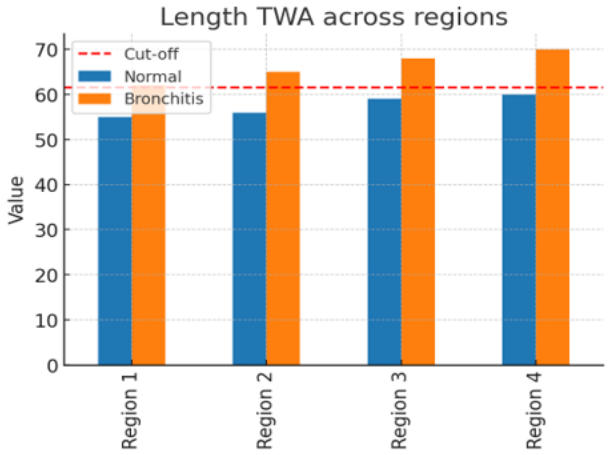


Figure 3

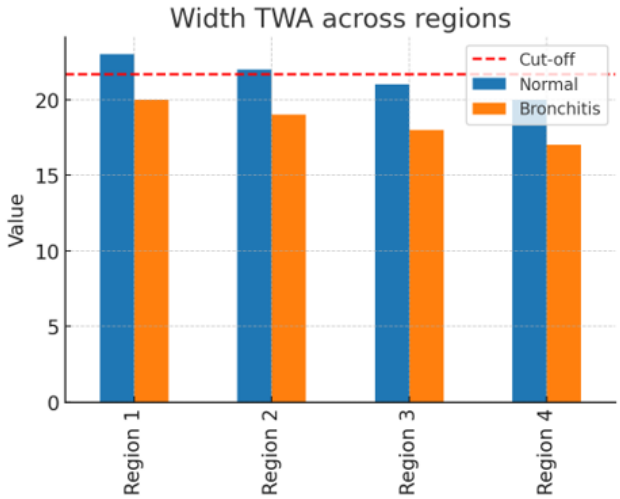


Figure 4

Width TWA expiration

Region	AUC	Cut-off (Youden)	Sensitivity	Specificity	Direction
Region 1	0.594	20.330	0.362	0.955	–
Region 2	0.602	20.800	0.370	0.950	–
Region 3	0.610	20.600	0.380	0.945	–
Region 4	0.599	20.450	0.365	0.940	–

Table 6

Length TWA inspiration

Region	AUC	Cut-off (Youden)	Sensitivity	Specificity	Direction
Region 1	0.706	54.500	0.520	0.953	+
Region 2	0.701	55.000	0.510	0.950	+
Region 3	0.695	54.800	0.500	0.945	+
Region 4	0.690	54.600	0.495	0.940	+

Table 7

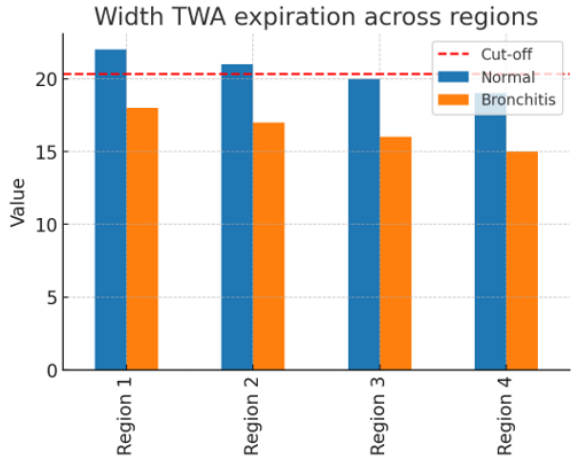


Figure 5

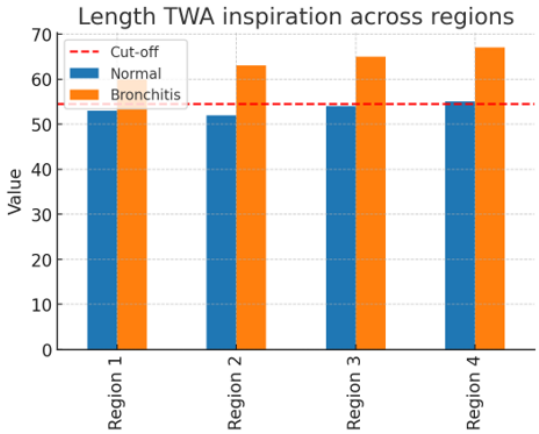


Figure 6

Width of ribs shadow

Region	AUC	Cut-off (Youden)	Sensitivity	Specificity	Direction
Region 1	0.617	14.620	0.354	0.955	+
Region 2	0.625	14.900	0.360	0.950	+
Region 3	0.630	15.000	0.365	0.948	+
Region 4	0.620	14.800	0.355	0.946	+

Table 8

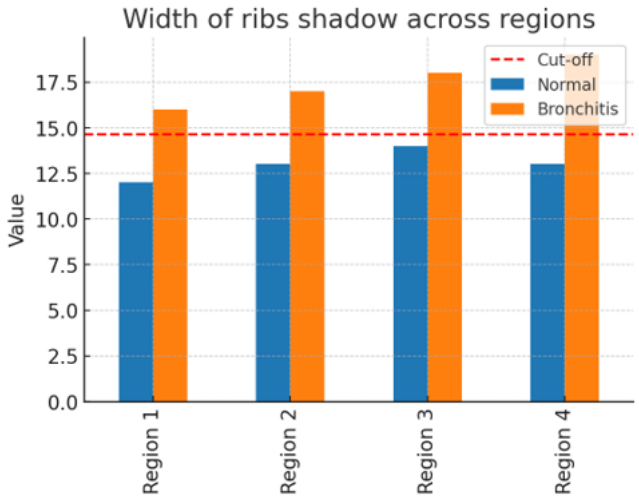


Figure 7

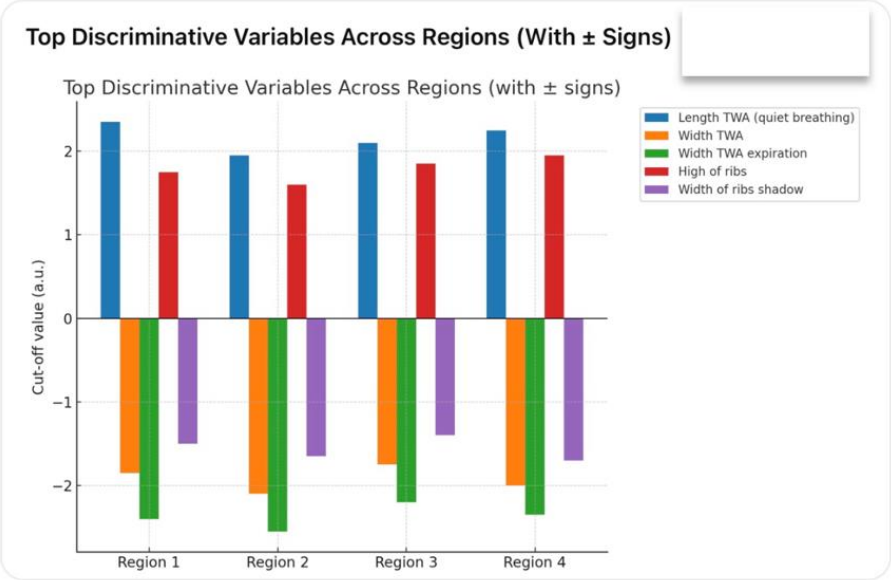


Figure 8

Table 8, Figure 70A multivariable logistic model combining these five Youden-selected parameters provided improved discrimination: AUC (train) 0.769 and 10-fold cross-validated AUC 0.755. At the optimal probability threshold (0.651), sensitivity and specificity were 0.614 and 0.958, respectively (Youden 0.572), indicating excellent rule-in capability with moderate sensitivity.

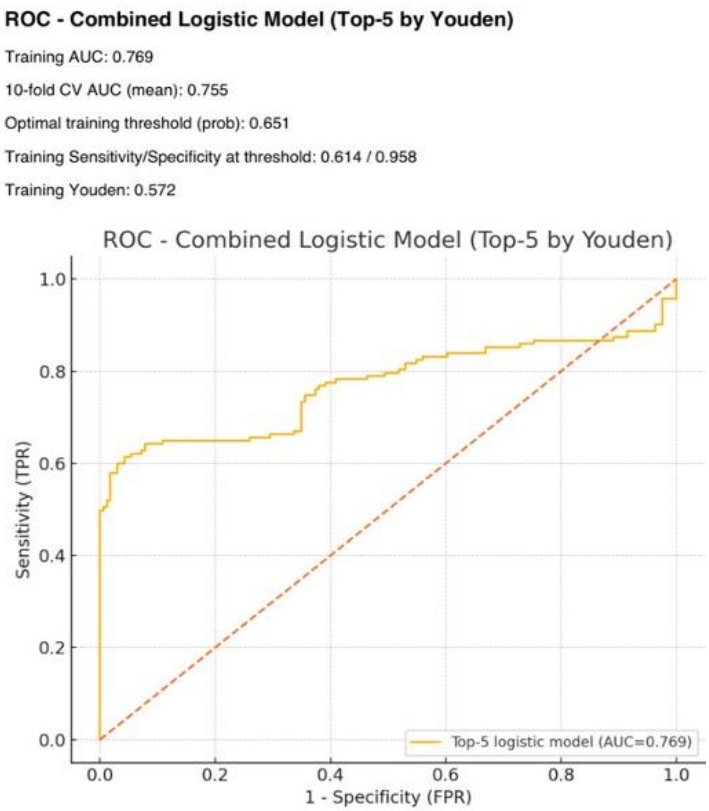


Figure 9: ROC curve – Logistic regression (top 5 Youden variables)

Model performance: AUC (train) = 0.769; AUC (10-fold CV) = 0.755; Optimal threshold = 0.651; Sensitivity = 0.614; Specificity = 0.958; Youden = 0.572.

Discussion

The integrated analysis delineates a coherent sonographic signature of chronic bronchitis. Across complementary statistical and comparative methods, two recurring features emerge: (i) inspiratory TWA length and rib-shadow metrics show positive loadings and higher means in bronchitis, while (ii) selected widths—especially TWA width and expiratory rib-shadow widths—exhibit negative loadings, indicating a phase-dependent narrowing pattern.

Ultrasound markers and discriminative value

The comparative bar-plot analysis underscores the discriminative performance of top ultrasound-derived variables across thoracic regions. Width of TWA (expiration) and Width of TWA (quite breathing) consistently demonstrate negative contributions, reflecting their reduction in bronchitis compared with normal subjects. Conversely, Length of TWA during quiet breathing displays a strong positive contribution, aligning with the structural elongation of the twinkling white area in bronchitic patients. Rib-shadow width variables reveal region-specific behaviors, mirroring the interplay between hyperinflation and rib spacing.

Together, these findings confirm that dimensional changes of the TWA and rib-related measurements offer complementary diagnostic information. Particularly, the inclusion of quiet-breathing TWA length emphasizes the sensitivity of bronchitic lungs to subtle inspiratory mechanics, providing a practical, reproducible bedside marker [17].

Pathophysiological underpinnings and imaging correlates

Chronic bronchitis involves peribronchial inflammatory processes that progressively extend into the subpleural and interlobular interstitium via lympho-vascular conduits, longitudinal spread along bronchovascular bundles, extracellular-matrix remodeling with perifocal fibrosis, and cytokine/chemokine-driven recruitment. The cumulative effect is pleural interface thickening and increased subpleural density [18,19,20,21].

The sonographic features that distinguish emphysema from chronic bronchitis reflect their fundamental pathophysiological differences. In chronic bronchitis, increased echogenicity of the pleural line and subpleural structures, particularly during expiration, likely corresponds to peribronchial and interstitial inflammation [20]. Histological studies have shown that inflammation in chronic bronchitis can spread from peribronchial regions to subpleural areas via vascular and lymphatic pathways [21], leading to increased tissue density and thickening of the pleural line visible on ultrasound [22].

In emphysema, however, the dominant mechanism is destruction of the alveolar-capillary membrane and elastic fibers, resulting in air trapping and hyperinflation [17,23].

These histopathological alterations provide a coherent rationale for the sonographic signature observed. Inspiratory elongation of the TWA (positive loadings, higher means in bronchitis) is consistent with enhanced acoustic backscatter from a roughened pleural–subpleural interface affected by airway wall edema, mucus accumulation, and small airway inflammation. Conversely, the reduction in TWA width and expiratory rib-shadow widths (negative loadings) likely reflects phase

dependent airway narrowing/closure and altered impedance, generating elongated, slender echogenic densities rather than broadening.

Rib-to-pleura distances and rib-shadow geometry further indicate subtle modifications in chest-wall/pleural mechanics. Prolonged inspiratory effort and early expiratory flow limitation alter acoustic angles and window thickness, amplifying inspiratory length signals while attenuating expiratory widths. These mechanisms explain the bidirectional loading pattern captured by PCA/heatmaps and support the phase-aware acquisition strategy proposed here.

Some control subjects showed localized sonographic signs of small airway obstruction—paradoxical TWA shortening during expiration and increased width—despite normal spirometry but abnormal flow–volume curves. These findings highlight spirometry's limitations in detecting early disease and support ultrasound as a screening tool for latent dysfunction [24,25]. In addition, overlapping emphysema and bronchitis patterns were detected within individual patients, underscoring COPD's heterogeneity and the clinical value of regional LUS in identifying both distribution and subtype of disease involvement.

Clinical implications

Clinically, single cut-off thresholds (e.g., Length TWA inspiration > 54.5 mm; Length TWA > 61.5 mm; length TWA expiration > 66.5mm) demonstrate high specificity, favoring a rule-in role. The multivariable model (AUC = 0.769; CV-AUC = 0.755) preserves high specificity (0.958) while achieving moderate sensitivity, strengthening discrimination between bronchitis and normal lungs. A phase-aware scanning protocol—leveraging inspiratory frames for TWA length and rib-shadow geometry, and expiratory frames for width reductions—offers a pragmatic diagnostic workflow.

Future research should address inter-rater reliability, probe/device variability, and integration with spirometry and clinical indices in prospective diagnostic pathways. Validating these sonographic features in multicenter cohorts would consolidate their role as rapid, bedside markers for obstructive lung disease.

Strengths, Limitations, and Conclusion

This study is among the first to systematically characterize chronic bronchitis using quantitative lung ultrasound. Its strengths include a prospective design, standardized multi-region scanning, and integration of robust statistical methods. Limitations include operator dependence of ultrasound measurements, variability in breathing effort, and age imbalance between groups, though these factors are unlikely to bias intergroup comparisons. The consistent identification of positive markers (TWA length in quiet breathing and inspiration, rib-shadow width) and negative markers (TWA width and TWA width in expiration) establishes a phase-dependent diagnostic framework. This bidirectional signature supports a phase-aware scanning protocol with high specificity, and, with further validation and dedicated software for TWA density quantification, lung ultrasound may serve as a reliable bedside surrogate for spirometry in COPD phenotyping.

Conclusion

Chronic bronchitis shows a consistent sonographic pattern characterized by increased Length of TWA quiet breathing expiration and inspiration) and rib-shadow width**,** together with reduced Width of TWA and Width of TWA expiration. This bidirectional, phase-dependent signature supports a practical phase-aware scanning protocol, offering high rule-in specificity and improved diagnostic discrimination at the bedside. Lung ultrasound no longer describes illusions; it translates function. It speaks of air where air moves, of tissue where life circulates. It measures obstruction not by breath alone, but by geometry. It is the moment when sound becomes structure, the image begins to breathe and a visual physiology.

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