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Research Article

Lung Ultrasound: An Initial Bedside 'Spirometry' Tool in Diagnosing Obstructive Syndrome

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Received Date: August 20, 2025 | **Accepted Date:** August 26, 2025 | **Published Date:** September 03, 2025

Citation: Perlat Kapisyzi, Elona Xhardo, Ornela Nuredini, Holta Tafa, Loreta Karaulli, et al, (2025), Lung Ultrasound: An Initial Bedside 'Spirometry' Tool in Diagnosing Obstructive Syndrome, *International Journal of Clinical Case Reports and Reviews*, 29(1); **DOI:10.31579/2690-4861/954**

Abstract:

Introduction

Chronic obstructive pulmonary disease (COPD), composed of emphysema and chronic bronchitis, is a leading global health burden. Differentiating these phenotypes at the bedside is essential, as emphysema management focuses on relieving hyperinflation and cautious oxygen titration, while chronic bronchitis requires secretion clearance, infection control, and tailored oxygen therapy. Conventional bedside tools lack accuracy for this purpose. Lung ultrasound (LUS), with novel pleural, sub pleural markers such as the Twinkling White Area (TWA) and rib shadow geometry, offers a potential solution. To our knowledge, this is the first study to investigate the role of LUS in phenotyping COPD.

Aim:

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. The current manuscript presents the lung ultrasound findings in emphysema.

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 and discussion

PCA revealed three major components explaining 61.6% of variance; the dominant contributor was TWA length during inspiration and expiration. ANOVA showed significant regional differences, with high expiration rib ($F = 60.77$, $p < 0.0001$) and TWA length expiration (up to −40% in Region 1) as leading discriminators. The best single variable was TWA length during expiration (cut-off: −50.2), with sensitivity 78.8%, specificity 85.1%, and AUC = 0.743. A five-variable logistic regression model achieved AUC = 0.728 (train), 0.716 (10-fold CV), with length TWA and W2 rib shadow as key predictors.

Conclusion:

Lung ultrasound enables accurate bedside identification of emphysematous remodeling, particularly through expiratory shortening and widening of TWA, rib shadow distortion, and pleural-rib distance reduction. These sonographic patterns are storytellers that reflect regional and phenotypic heterogeneity and may serve as real-time, non-invasive surrogates for spirometry in the evaluation of obstructive syndromes.

Key words: lung ultrasound; copd; emphysema; chronic bronchitis; twinkling white area; rib shadow; merlin space; spirometry surrogate; subpleural morphology; pca; roc analysis

Key Learning Points -Emphysema

- Lung ultrasound provides a practical bedside tool for identifying emphysema within the COPD spectrum when spirometry is not feasible.
- TWA length (quiet breathing and expiration) shows the strongest diagnostic performance, with sensitivity up to 0.79 and specificity up to 0.96 (AUC ~0.74).
- Rib-shadow geometry (W2) adds complementary value, reflecting increased pleural–subpleural depth and hyperinflation.
- TWA width markers contribute less sensitivity but maintain high specificity, reinforcing the multidimensional loading pattern.
- This sonographic signature mirrors alveolar destruction and distal air trapping, providing a phase-dependent, non-invasive correlate of emphysematous remodeling.

Introduction

Peripheral pulmonary diseases often present with subtle or absent clinical signs, limiting the sensitivity of auscultation and conventional imaging. Among obstructive syndromes, emphysema and chronic bronchitis may evolve insidiously and remain difficult to differentiate at the bedside. In this context, lung ultrasound (LUS) has emerged as a reliable, non-invasive technique capable of revealing pleural and subpleural abnormalities with clarity. Chronic Obstructive Pulmonary Disease (COPD) is a major global cause of morbidity and mortality [1], defined predominantly by two phenotypes: chronic bronchitis and emphysema. While chronic bronchitis is characterized by airway inflammation, mucus hypersecretion, glandular hypertrophy, and fibrotic remodeling, emphysema involves destruction of alveolar architecture and distal air trapping. Differentiating between these entities is clinically essential, as emphysema requires strategies directed at relieving hyperinflation and cautious oxygen titration, whereas chronic bronchitis demands urgent secretion clearance, infection control, and tailored oxygen therapy to prevent CO_2 retention. However, current bedside tools are limited in their ability to provide accurate phenotyping. Recent advances suggest LUS can extend diagnostic capabilities to the peripheral lung. Among novel markers, the Twinkling White Area (TWA) — reflecting pleural–subpleural 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.

Aims

This study aims to quantitatively assess sonographic markers—TWA length, width, density, rib shadow width (W, W2), rib-to-pleural line distance (“high of ribs”)—during rest, forced inspiration and expiration, across three groups: normal individuals, patients with emphysema, and those with chronic bronchitis. The goal is to identify specific sonographic features and their regional distribution that reliably differentiate COPD phenotypes. The current manuscript presents the lung ultrasound findings in emphysema.

Materials and Methods

In this prospective observational study, 105 subjects (25 controls, 40 with emphysema, 40 with chronic bronchitis) underwent LUS in four thoracic regions using a handheld Clarius scanner. Quantitative measurements were obtained during three respiratory phases. Statistical analysis included Principal Component Analysis (PCA), ANOVA, and multivariable logistic regression to identify the most discriminative variables.

Ultrasound Protocol

Equipment

Lung ultrasound examinations were performed using a handheld curved-array transducer (Clarius) with a frequency range of 2–5 MHz. The device was operated in lung preset mode, with an imaging depth of 18 to 20 cm.

Scanning Regions

Four lung zones were evaluated in each subject: two anterior regions, the posterior apical zone, and the lower posterior zone of the right lung, corresponding to regions 1, 2, 5, and 6 as defined by the BLUE protocol.

Measured Parameters

In each region, the following echographic features were assessed:

- The pleural line morphology and continuity
- The dimensions and density of the twinkling white area (TWA)
- Rib shadow spaces and rib height in relation to the pleural line
- Rib shadow width at the level of the pleura (W) and at the distal end of the TWA (W2)
- The vertical distance from the lower margin of the rib to the pleural line (rib height)
- Length and width of the TWA in various respiratory phases

Dynamic Assessment

All parameters were measured during three distinct respiratory states:

- Normal breathing
- Deep inspiration
- Deep Expiration

This allowed assessment of dynamic changes in TWA size, rib shadow width, and rib-to-pleura distances across different phases of respiration.

Image Acquisition and Analysis

The ultrasound scanning was performed by a single experienced sonographer to ensure inter-operator consistency. All images were analyzed using standardized Lung Ultrasound (LUS) software, enabling consistent quantification of echographic variables.

Data Collection and Statistical Analysis

Quantitative variables—including TWA dimensions, rib shadow widths, and pleural line distances—were recorded and expressed as means ± standard deviations.

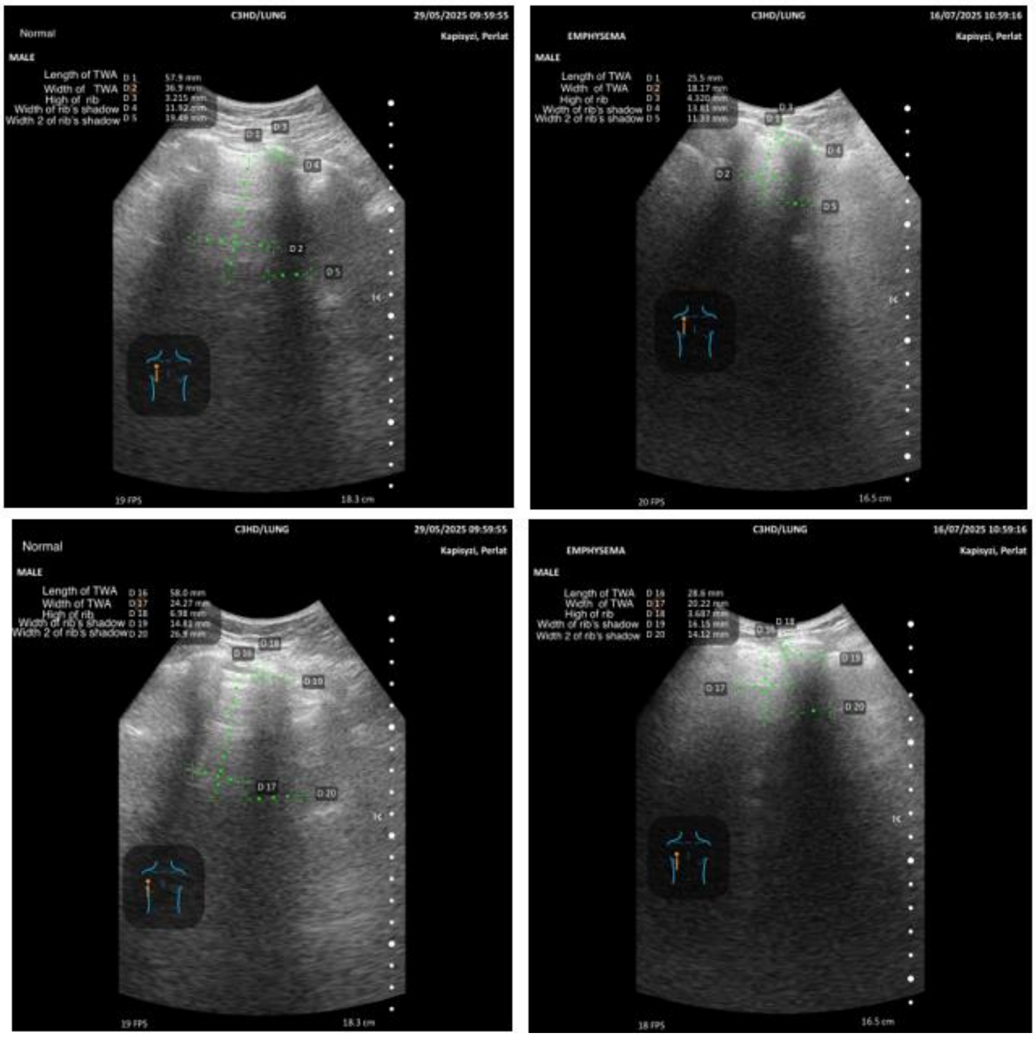
Statistical analysis was conducted using the Python programming environment, applying appropriate inferential tests based on the distribution and nature of the data.

Study Structure

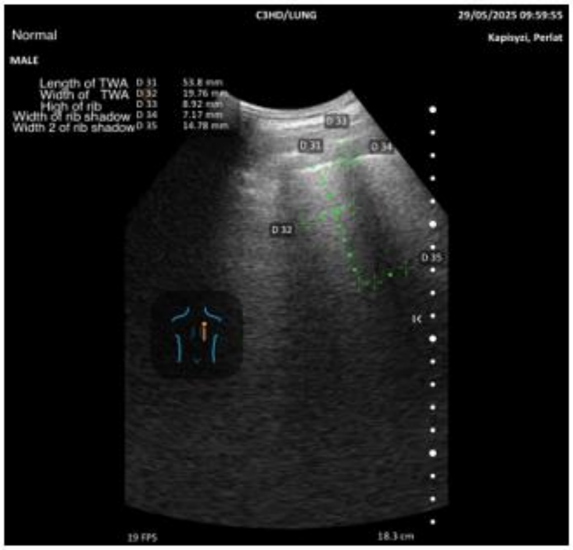
The study is structured into three main parts:

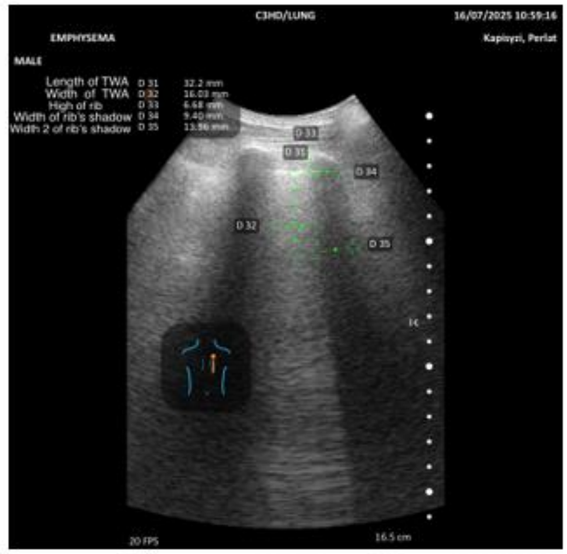
- The first part investigates the echographic features of pulmonary emphysema
- The second focuses on chronic bronchitis
- The third one studies the echographic features of pulmonary emphysema versus chronic bronchitis.

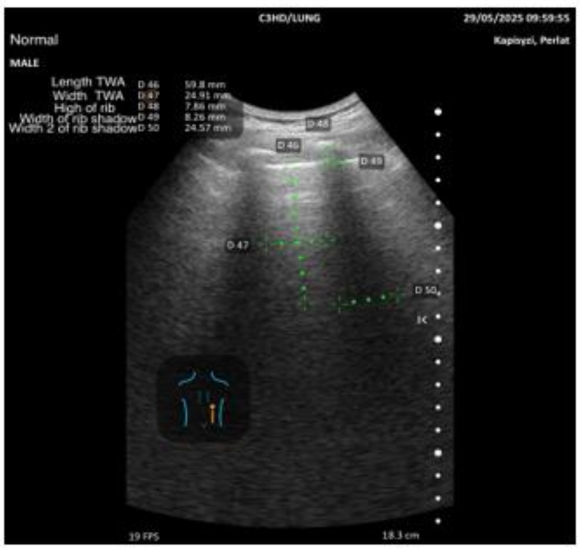
The methodology for quantifying regional variables in normal subjects and bronchitis patients is illustrated with pictograms and representative examples

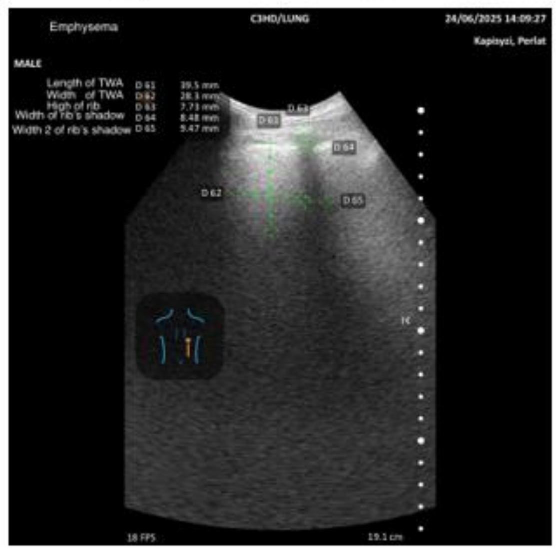


Results









Principal Component Analysis identified three main components explaining a cumulative 61.6% of the variance across the dataset. PC1, accounting for 25.6% of the total variance, was primarily driven by variables related to the Twinkling White Area (TWA), including its length and width during inspiration. PC2 (21.5%) captured variations in rib height during respiratory phases, while PC3 (14.5%) reflected structural parameters such as W2 ribs during inspiration/expiration and rib shadow dimensions. (Table 1)

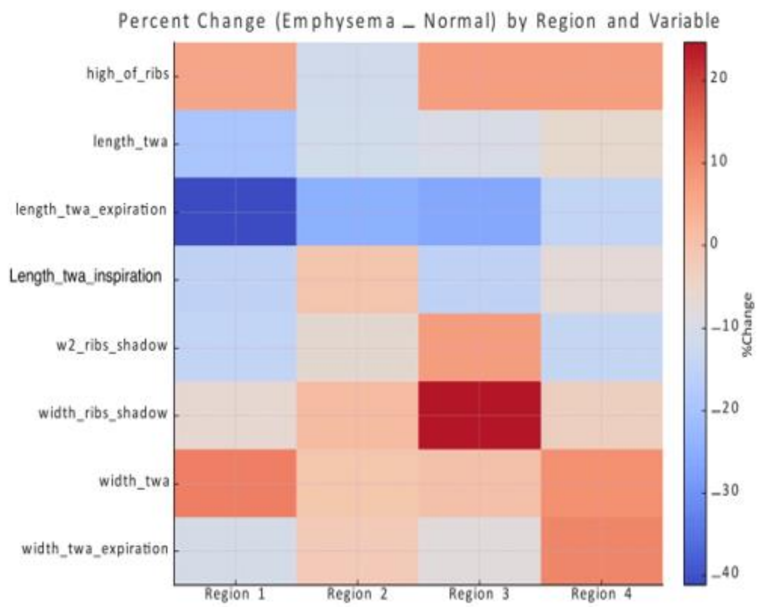
Principal Component	Explained variance	Top varibles
		Length TWA inspiration
		Length TWA
PC1	25.60%	Width TWA
		Width TWA inspiration
		W2 ribs expiration
		High rib expiration
		High rib inspiration
PC2	21.50%	High of rib
		Width TWA
		Width TWA expiration

		W2 ribs expiration
		W2 ribs inspiration
PC3	14.50%	High of rib
		W2 ribs shadow
		High of rib expression

Table 1: Principal Components Analysis

The percent change heatmap (emphysema vs. normal) revealed significant regional alterations. The length of TWA during expiration showed the most pronounced reduction in emphysematous subjects, especially in Region 1 (up to −40%), suggesting localized expiratory collapse. In contrast, increases in width of TWA and rib shadow width were observed, particularly in Regions 3 and 4, indicating possible compensatory widening or distortion of intercostal spaces. (Heatmap)

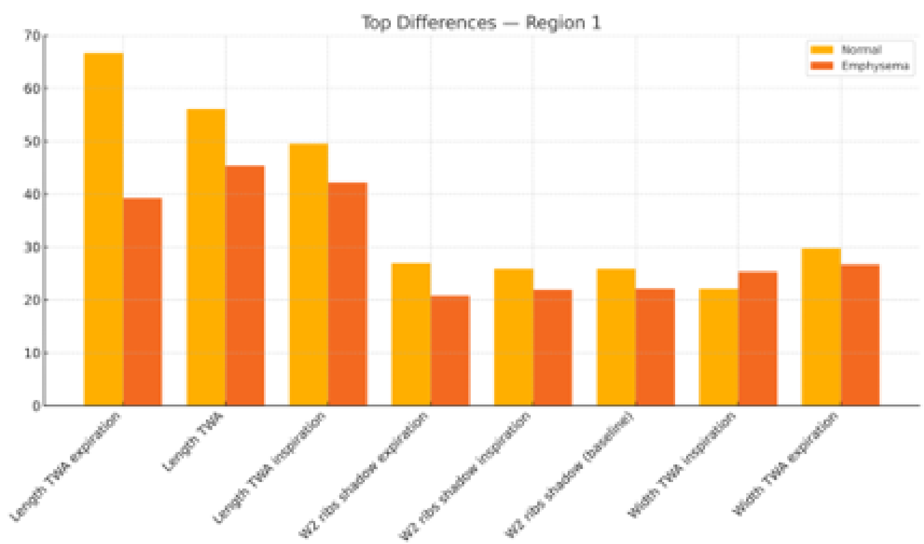
HEATMAP

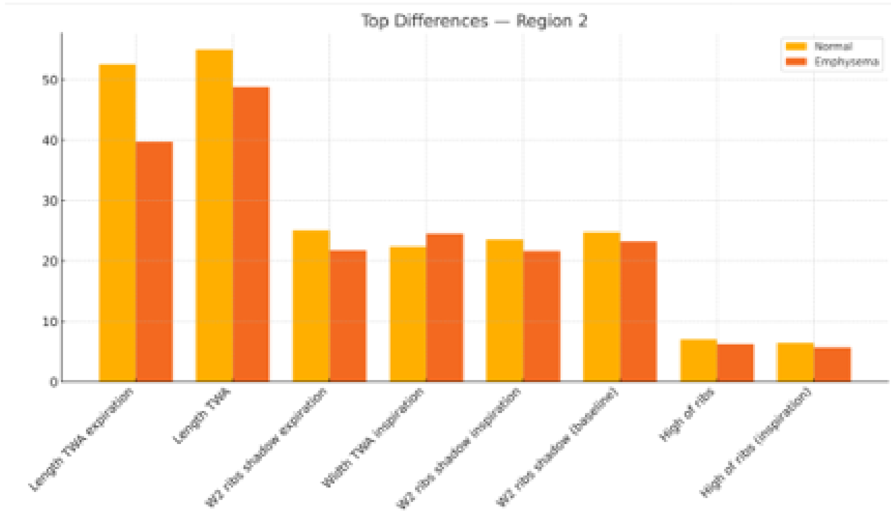


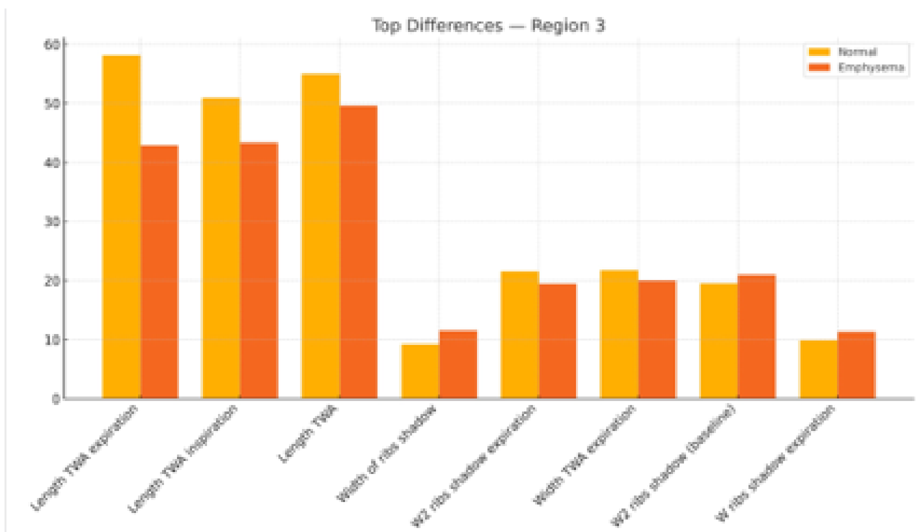
One-way ANOVA supported these findings, with several variables showing statistically significant inter-regional differences. High expiration rib ($F = 60.77$, p 0.0001), high of ribs ($F = 42.91$, $p < 0.0001$), and high inspiration rib ($F = 39.94$, $p < 0.0001$) demonstrated the highest discriminatory power. Importantly, many of the variables identified as principal contributors in PCA also emerged as statistically significant in ANOVA, reinforcing their relevance for differentiating normal and emphysematous patterns (Table 2).

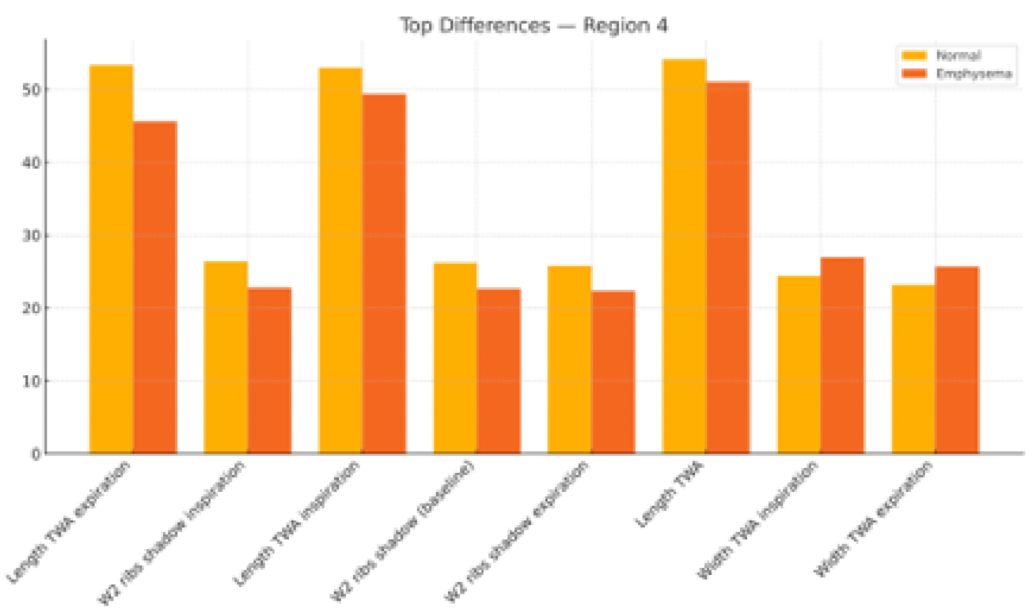
One way ANOVA	Table 2	
Variables	F-static	p-value
High of rib expiration (	60.7712	0
High of rib	42.9065	0
High of rib inspiration	39.9357	0
Width of ribs shadow	22.0702	0
Width TWA expiration	21.2147	0
Width TWA	20.2112	0
W rib shadow inspiration	18.1643	0
W rib shadow expiration	16.2158	0
Width TWA inspiration	15.41	0
W2 ribs shadow	13.9218	0
Length TWA inspiration	13.0649	0
Length TWA expiration	9.6362	0
W2 ribs shadow inspiration	9.0976	0
W2 ribs shadow expiration	6.8375	0.0002
Length TWA	6.6461	0.0002

Bar plot analyses of the top discriminative variables across thoracic regions revealed consistent and marked differences between subjects with emphysema and normal controls. The most significant divergence occurred in the length of TWA during expiration, which emerged as the leading differentiator in all four regions, with the greatest absolute difference in Region 1. Region 1 also showed strong separation based on TWA width, rib shadow width, and height of ribs, suggesting early upper-anterior morphological distortion. In Region 2, a similar trend was observed, with additional emphasis on W2 ribs shadow and TWA width during expiration, indicating expiratory dysfunction and structural widening. Regions 3 and 4 exhibited distinct patterns, with Region 3 highlighting rib shadow width and TWA width during expiration as dominant variables, and Region 4 showing a substantial increase in W2 ribs shadow, suggesting posterior-lateral remodeling. Across all regions, rib height and TWA configuration metrics consistently distinguished emphysematous from normal morphology, underscoring their diagnostic value. [Regions-1,2,3,4]




Top Differences — Region 2
Normal
Emphysema
0
10
20
30
40
50
Length TWA expiration
Length TWA
W2 ribs shadow expiration
Width TWA inspiration
W2 ribs shadow inspiration
W2 ribs shadow (baseline)
High of ribs
High of ribs (inspiration)


Top Differences — Region 3
Normal
Emphysema
0
10
20
30
40
50
60
Length TWA expiration
Length TWA inspiration
Length TWA
Width of ribs shadow
W2 ribs shadow expiration
Width TWA expiration
W2 ribs shadow (baseline)
W ribs shadow expiration


Top Differences — Region 4
Normal
Emphysema
0
10
20
30
40
50
Length TWA expiration
W2 ribs shadow inspiration
Length TWA inspiration
W2 ribs shadow (baseline)
W2 ribs shadow expiration
Length TWA
Width TWA inspiration
Width TWA expiration

Using Youden's J index, we identified the top-performing variables based on either sensitivity or specificity for distinguishing emphysema from normal subjects. The three most sensitive variables were:

- Length of TWA during expiration (cut-off: −50.20), achieving a sensitivity of 78.8% and
- specificity of 85.1% (AUC = 0.743);
- W2 ribs during expiration (cut-off: 22.91), with moderate sensitivity (64.1%) and specificity (73.3%);
- Length of TWA at rest (cut-off: −50.40), which demonstrated high specificity (96.7%) despite a slightly lower sensitivity (62.3%), with an AUC of 0.740.[figure 2]

Conversely, variables selected for maximal specificity included:

- Length of TWA during inspiration (cut-off: 57.30), which achieved perfect specificity (1.000) but low sensitivity (17.4%);
- Width W1 at rest (cut-off: 15.15), with specificity of 98.6% and sensitivity of 18.0%;
- Rib height at rest (cut-off: 4.98), reaching specificity of 97.6% but limited sensitivity (22.0%).

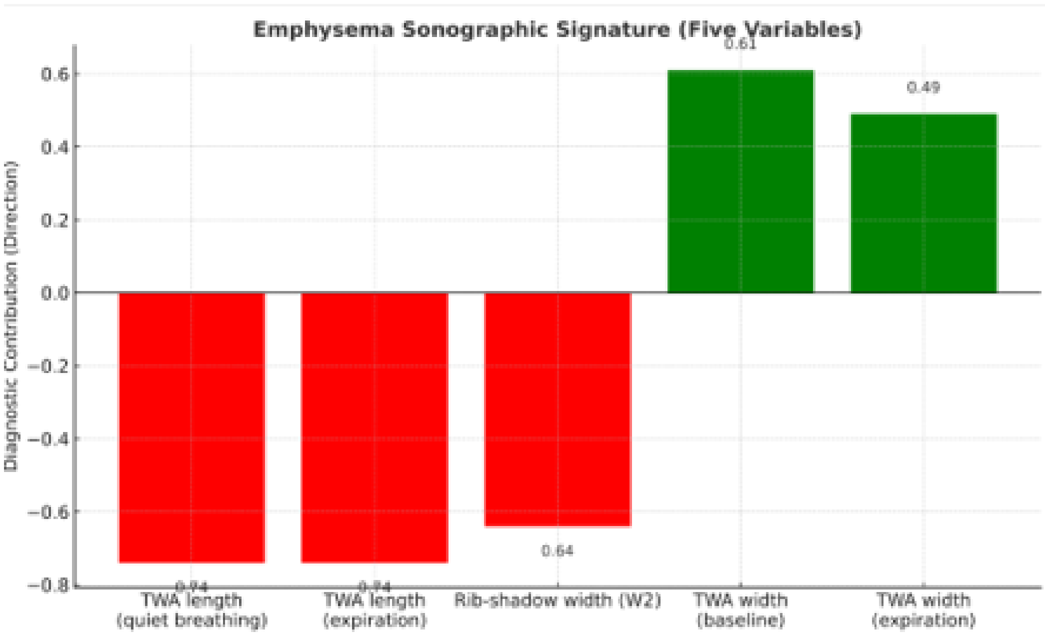


Figure 2

These findings suggest that variables related to expiratory morphology (especially TWA length) are more balanced in terms of diagnostic performance, while highly specific variables may be useful in ruling in emphysema when present (Table 3 and 4)

Table 3 Top 3 by Sensitivity (Corrected Cut-offs)

Variable	Cut-off	Sens	Spec	AUC
Length_TWA_exp	−50.20	0.788	0.851	0.743
W2_exp	−22.91	0.641	0.733	0.629
Length_TWA_rest	−50.40	0.623	0.967	0.740

Table 4 Top 3 by Specificity (Unchanged)

Variable	Cut-off	Sens	Spec	AUC
Length_TWA_insp	57.30	0.174	1.000	0.421
W1_rest	15.15	0.180	0.986	0.543
High_rest	4.98	0.220	0.976	0.502

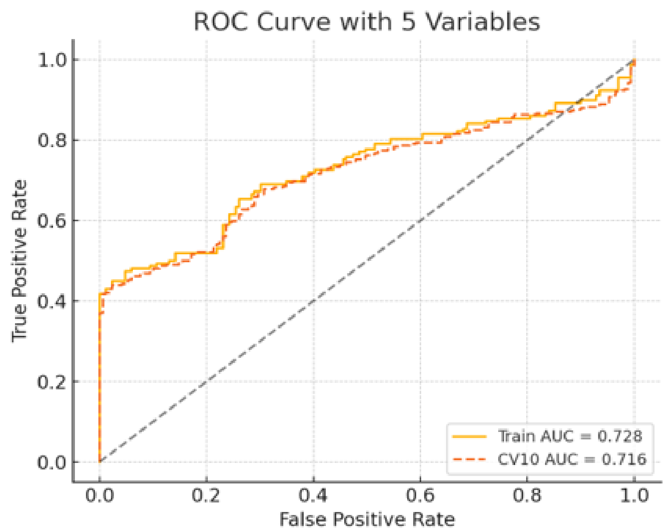
A logistic regression model was constructed to differentiate emphysema from normal subjects using five ultrasound-based variables. The trained model achieved an Area Under the Curve (AUC) of 0.728, and 0.716 under 10-fold cross-validation, showing both good discrimination and internal validity.

Cut-off thresholds were determined via the Youden Index, balancing sensitivity and specificity. Among the features, length_twa demonstrated the highest individual AUC (0.738) and Youden Index (0.592), followed by w2_ribs_shadow. While width_twa_expiration showed limited sensitivity (0.229), its high specificity (0.976) made it clinically valuable in confirming true-negative cases.

The final regression model included five variables for several methodological and clinical reasons: complementary value of individually weaker variables (e.g., width_twa_expiration), maximal specificity gain, better multidimensional representation of sonographic pathology, and improved cross-validation performance. For instance, despite its lower individual AUC, width twa expiration added discriminative power in combination with other variables. [Table 5, figure 3]

Variable	Cut-off (Youden)	Sensitivity (Emphysema)	Specificity (Normal)	AUC (Individual)
width_twa	26,7	0,43	0,964	0,606
width_twa_expiration	29,5	0,229	0,976	0,494
w2_ribs_shadow	-23,41	0,627	0,793	0,643
length_twa	-50,4	0,627	0,964	0,738
length_twa_expiration	-50,2	0,788	0,851	0,743

Figure 3



Discussion

General Diagnostic Insights from LUS

This study demonstrates that emphysema is characterized by distinct and regionally specific morphological changes detectable through lung ultrasound. A consistent and pronounced reduction in the length of the Twinkling White Area (TWA) during expiration—particularly in anterior upper regions—emerges as a hallmark of early loss of elastic recoil and dynamic airway collapse. These features align with previously described pathophysiological patterns of emphysema, where premature airway closure during forced expiration is a key mechanism [17]. In contrast to TWA shortening, a concomitant increase in TWA width and rib shadow width was observed, especially in posterior regions. This may reflect compensatory remodeling of the thoracic cage due to hyperinflation [18]. Changes in rib height and the rib-to-pleural line distance also proved discriminative, possibly reflecting altered intrathoracic pressure dynamics and parenchymal integrity. Notably, expiratory-phase variables, particularly TWA length, offered the most favorable balance of sensitivity and specificity. Meanwhile, variables measured at rest or during inspiration showed very high specificity but low sensitivity, supporting their role in phenotype confirmation rather than screening. Multivariable logistic regression demonstrated that a combination of five variables improved predictive performance and diagnostic reliability. The regional heterogeneity of ultrasound findings mirrors CT-based descriptions of emphysema's topographic variability [19]. This supports the concept that numeric cut-offs for ultrasound variables may have diagnostic value only when interpreted within their anatomical context. Importantly, this is the first study to evaluate the diagnostic and phenotypic potential of Merlin space components—specifically TWA and rib shadow parameters—using lung ultrasound in obstructive pulmonary syndromes. The approach used here demonstrates that lung ultrasound may serve not only as a detection tool but also as a bedside surrogate for functional phenotyping of COPD.

Pathophysiological Differentiation Between Emphysema and Chronic Bronchitis

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]. This explains the characteristic shortening of the TWA during expiration, increase in width of TWA, as well as the increased distance between the ribs and the pleural line. Rib shadows become shorter, wider or nerrower according the regions, likely reflecting changes in intercostal spacing due to altered chest wall and lung compliance. Ultrasound patterns also varied according to emphysema subtype. In panacinar emphysema, there was global shortening of the TWA and loss of definition of its borders. In centriacinar emphysema, pleural distortion and irregular rib shadows were more prominent, while in periacinar emphysema, changes were subtle and localized, often limited to posterior-lateral zones.

Several control subjects displayed localized sonographic signs of small airway obstruction—such as paradoxical shortening of TWA during expiration and increased width—despite having normal spirometry but not normal curve configuration. These findings align with known limitations of spirometry in detecting early airway disease and support the emerging role of ultrasound in screening for latent dysfunction [24,25]. Furthermore, coexisting patterns of emphysema and chronic bronchitis were observed in several regions within individual patients, reinforcing the heterogeneity of COPD. This highlights the clinical relevance of regional LUS, which may help identify not only the presence but also the distribution and subtype of disease involvement. Taken together, these findings suggest that lung ultrasound, when applied with dimensional and phase-specific metrics, offers a dynamic, region sensitive, and non-invasive method to classify obstructive phenotypes. The ability to detect expiratory collapse, pleural, twinkling white area and rib's shadow distortion, or inflammatory thickening at the bedside opens new perspectives for COPD diagnosis and management.

Conclusion:

Lung ultrasound enables accurate bedside identification of emphysematous remodeling, particularly through expiratory shortening and widening of TWA, rib shadow distortion, and pleural-rib distance reduction. These sonographic patterns are storytellers that reflect regional and phenotypic heterogeneity and may serve as real-time, non-invasive surrogates for spirometry in the evaluation of obstructive syndromes and specifically emphysema phenotype.

Clinical Application

This study highlights a consistent sonographic pattern for emphysema within the Merlin space. The most discriminative variables were reduced TWA length, decreased rib-shadow width (W2), and increased TWA width, particularly in expiration. Among these, TWA length showed the best diagnostic performance (AUC ~0.74), while rib-shadow width and TWA width provided complementary value. These phase-dependent reductions reflect pleural– sub pleural remodeling and distal air trapping characteristic of emphysema. Although preliminary, integrating these markers into bedside scanning may support recognition of hyperinflation and guide clinical management when spirometry is unavailable.

Strengths, Limitations, and Conclusion

This study is among the first to systematically characterize emphysema 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 negativ markers (TWA length in quiet breathing and inspiration, W2 rib-shadow width) and positive 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.

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DOI:10.31579/2690-4861/954