

Diaphragm Assessment by Multimodal Ultrasound Imaging in Patients with Chronic Obstructive Pulmonary Disease: A Prospective Observational Study

Tianjie Zhang¹, Yan Liu¹, Mengmei Wang², Miao He¹, Min Yu¹, Yi Li¹, Ye Song¹

¹Department of Ultrasonography, Shanghai University of Medicine and Health Sciences Affiliated Zhoupu Hospital, Shanghai, 201318, People's Republic of China; ²Department of Respiratory Diseases, Shanghai University of Medicine and Health Sciences Affiliated Zhoupu Hospital, Shanghai, People's Republic of China

Correspondence: Ye Song, Email songy_18@sumhs.edu.cn

Background: Chronic obstructive pulmonary disease (COPD) patients often exhibit diaphragmatic dysfunction which can be effectively assessed using ultrasonography. This study aims to evaluate diaphragmatic function in COPD patients through multimodal ultrasound imaging and to identify key parameters.

Methods: This study consecutively enrolled 75 COPD patients and 75 healthy subjects. Measurements of diaphragm contraction, motion-related parameters and tissue Doppler imaging (TDI) parameters were conducted and recorded. Clinically relevant data were collected. Baseline demographics, spirometry results, and ultrasound data were compared between COPD patients and healthy subjects. Receiver Operating Characteristic (ROC) curve was constructed to evaluate the diagnostic value of diaphragmatic ultrasound parameters for COPD patients.

Results: Diaphragm at the end of tidal inspiration (DT_insp), diaphragm thickening fraction (DTF), diaphragmatic excursion during deep breathing (DE_DB) were significantly lower in COPD patients than in healthy subjects, conversely diaphragmatic excursion during quiet breathing (DE_QB), diaphragmatic contraction velocity during quiet breathing (DCV_QB), peak contraction velocity (PCV), peak relaxation velocity (PRV), velocity-time integral (VTI) were higher in COPD patients than in healthy subjects. DT_insp, DTF, DE_DB values decreased as COPD severity increased, conversely, DE_QB, DCV_QB, PCV, PRV and VTI exhibited an upward trend with COPD severity. DTF was positively correlated with FEV1 predicted ($r=0.713$, $P=0.000$), DE_QB ($r=-0.740$ and -0.889), PCV ($r=-0.609$ and -0.778), PRV ($r=-0.686$ and -0.857) were negatively correlated with FEV1/FVC and FEV1 predicted ($P=0.000$). Meanwhile, DE_QB, DCV_QB, PCV and PRV exhibited superior performance in predicting COPD, with AUC values of 0.906, 0.833, 0.859 and 0.833, respectively. DE_QB exhibited 81.33% sensitivity, while DTF, DE_QB, DE_DB, PCV and PRV showed high specificity (98.67%, 90.67%, 96.00%, 97.33% and 100%, respectively).

Conclusion: Multimodal ultrasound imaging offers a sensitive approach for detecting diaphragmatic dysfunction in COPD patients. Diaphragm ultrasound parameters correlate with pulmonary function and COPD severity, indicating that these parameters can provide valuable insights into disease progression and management.

Keywords: diaphragm assessment, multimodal ultrasound imaging, diaphragmatic dysfunction, COPD

Introduction

Chronic obstructive pulmonary disease (COPD) represents a significant global public health challenge and poses a grave risk to human health.¹⁻³ This condition is marked by a progressive obstruction of the airways, because the diaphragm serves as the mainly principle muscle of inspiration, its function plays a critical role in the pathophysiology of COPD.

Evaluating diaphragm function is crucial for COPD patients, ultrasound offers a noninvasive, real-time visualization method for assessing diaphragm function and is increasingly used in clinical practice.⁴⁻⁷ The reliability of this technique

has been extensively examined^{8,9} and several studies^{10–12} suggest that ultrasound can aid in evaluating and monitoring diaphragmatic dysfunction in COPD patients. Nonetheless, data specific to COPD patients remain limited. In this study, we assessed various parameters related to diaphragm contraction and motion, as well as tissue Doppler imaging (TDI) parameters. The aim of this study is to compare all of this diaphragm ultrasound parameters in COPD patients and healthy subjects to investigate the effectiveness of the diaphragm ultrasound method for COPD patients and provide valuable ultrasound parameters for clinical evaluation. In addition, examine the relationship between these parameters and pulmonary function test parameters.

Methods

Study Procedure

We prospectively enrolled patients coming to the Department of Respiratory Diseases of Zhoupu Hospital in Pudong New Area, Shanghai, during the period from January 2024 to December 2024. At the same time, healthy volunteers with similar age and BMI and without any diagnosed disease were selected as the control group. Informed consent was obtained from all subjects who agreed to participate in the observational study. All procedures were performed in accordance with the Declaration of Helsinki, and the study has been approved by the Ethics Committee of Zhoupu Hospital (2024-C-013-E01). Baseline characteristics data such as age, gender, body mass index (BMI) of all participants were recorded, spirometry test results and diaphragm ultrasound were collected. The flowchart of the subject process is shown in Figure 1.

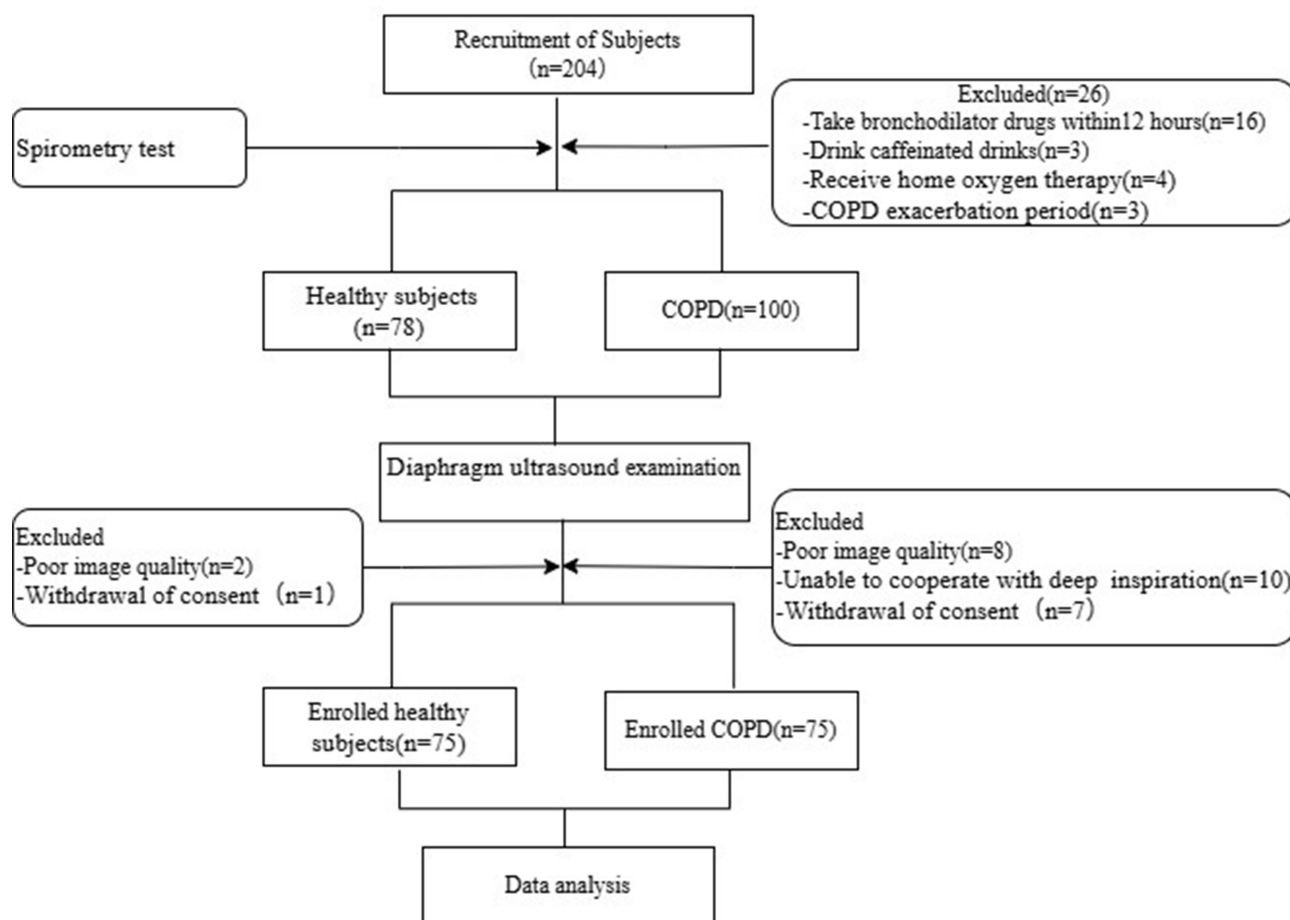


Figure 1 The flowchart of the subject process.

Subjects

COPD patients were eligible if they had a confirmed COPD diagnosis by a specialist in accordance with the GOLD guideline for COPD.¹ Eligibility also required a post-bronchodilator spirometry result showing a forced expiratory volume in one second (FEV1) to forced vital capacity (FVC) ratio of less than 70%. Eligibility had to be in a stable condition with no exacerbation at least for the previous month. The exclusion criteria were as follows: (1) age < 18 years old; (2) congestive heart failure, neuromuscular disease, history of cerebrovascular events; (3) recent use of systemic steroids for a COPD exacerbation within the last month, and those receiving home oxygen therapy or noninvasive mechanical ventilation. (4) patients with conditions such as apnea, active malignancy, or use of medications affecting bone metabolism or muscle strength. (5) bioimpedance analysis (BIA) was contraindicated (eg, presence of a cardiovascular stent, pacemaker, joint prosthesis, or visible oedema).

Healthy subjects without any diagnosed disease and nonsmokers were included in the study. Exclusion criteria: (1) age < 18 years old; (2) pregnant women; (3) diaphragmatic palsy, phrenic nerve injury, diaphragmatic bulging; (4) a history of chest and abdomen trauma in the past 3 months.

All volunteers unable to cooperate with deep inspiration and forced expiration manoeuvres were excluded in the study.

Ultrasonic Diaphragmatic Examination

Ultrasonic diaphragmatic examination was performed after spirometry was well done and before therapy. In addition, ultrasonic diaphragmatic examination on the right side of diaphragm in the liver as the acoustic window, volunteers take supine position.

Resona 8 ultrasound system (Mindray Medical International, China), with convex array probe SC6-1, linear array probe L11-3U, phased array probe M9CV was used for data collection; All the ultrasound data were collected by two senior sonographers with 10 years of experience in lung ultrasound.

Diaphragm Contraction Related Parameters

The 3–11 MHz linear array transducer was used for the assessment of diaphragm thickness (DT) and diaphragm thickening fraction (DTF) in the right anterior axillary line at the 8–9 intercostal space. The diaphragm is a hypoechoic tissue structure located between these two linear echoes and normally moves in the direction of the probe during inspiration. DT was measured by placing electronic calipers just inside the two hyperechoic lines where the lines were most parallel and the DT at the end of inspiration and expiration was measured by B-mode, respectively (Figure 2). DTF was calculated as a percentage using the following formula:

$DTF = [Diaphragm\ thickness\ at\ the\ end\ of\ tidal\ inspiration\ (DT-insp) - diaphragmatic\ thickness\ at\ the\ end\ of\ tidal\ expiration\ (DT-exp)] / DT-exp.$

Diaphragmatic Motion-Related Parameters

The 1–6MHz convex array probe was held and placed at the intersection of the right midclavicular line or right anterior axillary line and the lower edge of the costal arch, and pointed to the medial, cephalic and dorsal sides. After the patient was asked to breathe smoothly, satisfactory two-dimensional images were obtained. The ultrasound beam was perpendicular to the posterior 1/3 of the diaphragm, and M-ultrasound was used to monitor the movement of the right diaphragm. Diaphragm excursion (DE) and time (T) in a single breath was obtained by using the menu of measurement speed (Figure 3), which marked the trough and peak of the waves. Diaphragmatic contraction velocity (DCV) was calculated.

$$DCV = DE / T.$$

The data were measured separately during quiet and deep breathing, and the measurements were averaged three times.

TDI Parameters

The 9 MHz phased array probe was placed in the subcostal position between the mid-clavicular and anterior axillary lines as the ultrasound beam to reach perpendicularly the middle or posterior third of the hemidiaphragm. The sample volume was

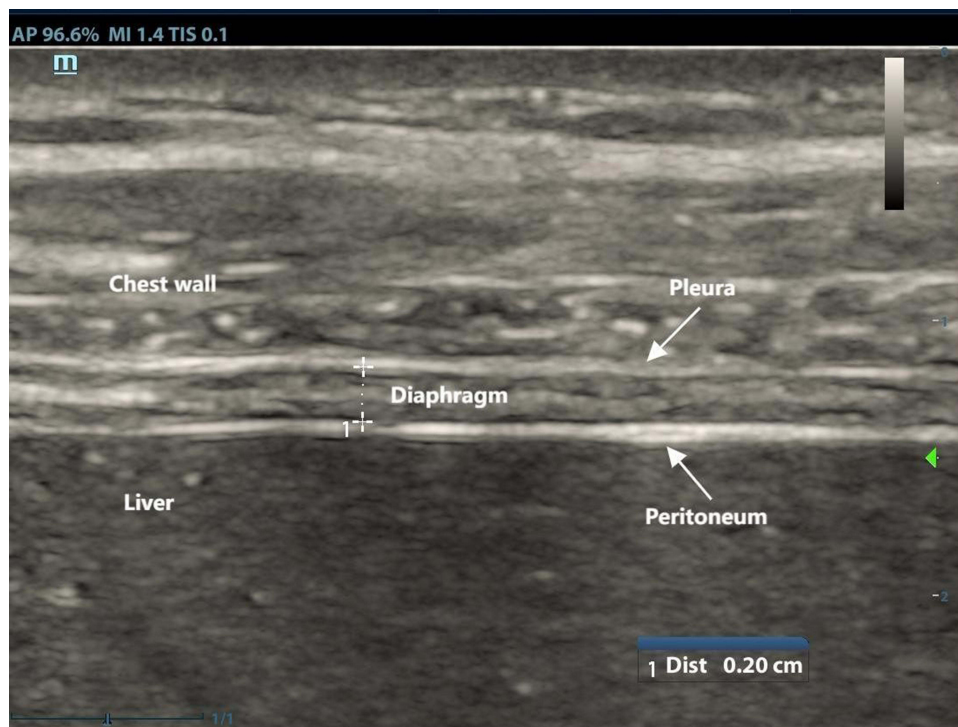


Figure 2 Measurement of diaphragm thickness in B mode.

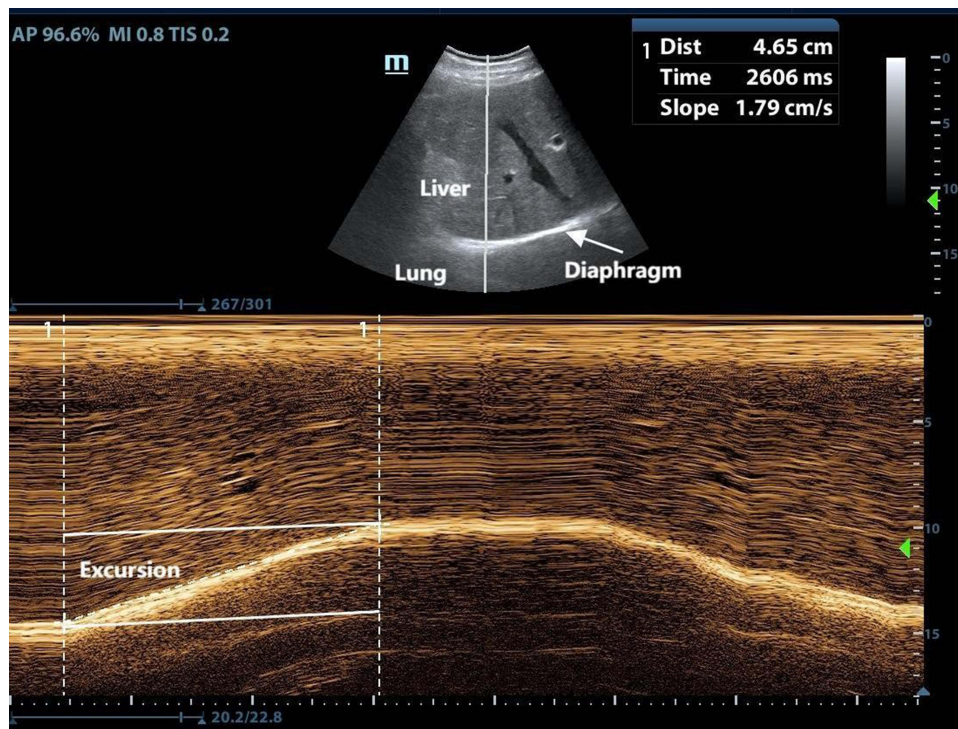


Figure 3 Measurement of diaphragm mobility in M mode.

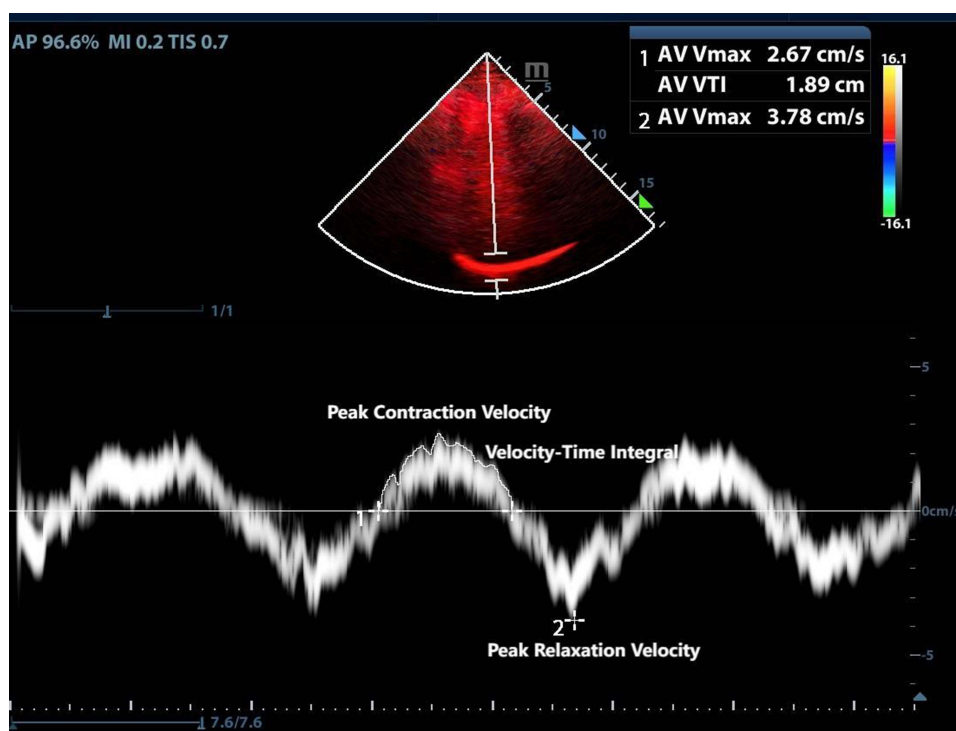


Figure 4 Diaphragmatic Tissue Doppler Imaging (TDI) during quiet breathing. Diaphragmatic TDI exhibits two waves, one during diaphragmatic contraction (above the baseline) and one during diaphragmatic relaxation (below the baseline).

initially selected at 20.0 mm to incorporate the whole range of diaphragmatic motion. The velocity scale used was 10 cm/sec to match the lower velocity of the moving diaphragm. The TDI was commenced, and the data regarding diaphragm motion such as peak contraction velocity (PCV), peak relaxation velocity (PRV), velocity-time integral (VTI) were collected (Figure 4).

Statistical Analysis

Statistical analyses were performed using SPSS (version 23.0) and MedCalc (version 20.104). Measurement data were expressed as ($\bar{x} \pm s$), and comparison between the two groups was analyzed using the group *t* test. The count data were expressed as relative numbers, and the comparison between the two groups was analyzed by chi-square test. Pearson correlation analysis was conducted to examine the relationships between continuous variables. The predictive power of each parameter for COPD was evaluated based on the AUC. The cut-off value was used as the diagnostic reference. $P < 0.05$ was considered statistically significant.

Results

General Conditions

There were 75 COPD patients (60 males and 15 females) and 75 healthy subjects (60 males and 15 females) completed all data collection. Upon comparing the age, BMI, sex of individuals, there was no significant difference between COPD patients and healthy subjects ($p > 0.05$). There was a significant difference between COPD patients and healthy subjects in terms of FEV1/FVC and FEV₁ predicted ($p < 0.05$) (Table 1).

There were significant differences between the two groups in all diaphragm ultrasound parameters except DT_{exp} and diaphragmatic contraction velocity during deep breathing (DCV_{DB}) ($p < 0.05$) (Table 2). The DT_{insp}, DTF, diaphragm excursion during deep breathing (DE_{DB}) were significantly lower in COPD patients than in healthy subjects, but the diaphragm excursion during quiet breathing (DE_{QB}), diaphragmatic contraction velocity during quiet breathing (DCV_{QB}), PCV, PRV and VTI were higher in COPD patients than in healthy subjects, indicating a more pronounced respiratory movement compared to healthy subjects during quiet breathing.

Table 1 Basic Information Compared Between Healthy Subjects and Patients with Stable COPD

Variables	Healthy Subjects (75)	COPD Patients (75)	P
Age (years)	69.72±6.99	69.04±7.72	0.573
Body mass index (kg/m ²)	23.50±2.90	22.54±3.40	0.065
Sex [% (n)]			0.581
Female	20.0(15)	20.0(15)	
Male	80.0(60)	80.0(60)	
FEV ₁ /FVC (%)	85.27±3.97	56.78±9.51	0.000
FEV ₁ predicted (%)	95.64±3.30	55.10±20.70	0.000

Note: Data expressed as mean ± standard deviation.

Abbreviations: FEV₁, forced expiratory volume in 1 second; FVC, forced vital capacity.

Table 2 Comparison of Healthy Subjects and Patients with Stable COPD According to Ultrasound Measurements

Parameters	Healthy Subjects (75)	COPD Patients (75)	P
B-mode_Thickness (cm)			
DT_exp (cm)	0.17±0.03	0.18±0.04	0.732
DT_insp (cm)	0.37±0.08	0.33±0.10	0.007
DTF (%)	112.25±18.64	87.28±33.33	0.000
M-mode_Excursion			
DE_QB (cm)	1.35±0.11	1.91±0.48	0.000
DCV_QB (cm/s)	1.16±0.31	1.75±0.66	0.000
DE_DB (cm)	5.77±0.81	5.21±1.28	0.002
DCV_DB (cm/s)	2.79±0.85	2.61±0.80	0.168
TDI parameters			
PCV (cm/s)	1.94±0.24	3.06±1.31	0.000
PRV (cm/s)	1.83±0.25	3.34±1.56	0.000
VTI	1.87±0.39	2.35±0.67	0.000

Note: Data expressed as mean±standard deviation.

Abbreviations: DT-exp, Diaphragm thickness at the end of tidal expiration; DT-insp, Diaphragm thickness at the end of tidal inspiration; DTF, Diaphragm thickening fraction; DE, Diaphragm excursion; DCV, Diaphragmatic contraction velocity; QB, quiet breathing; DB, deep breathing; PCV, Peak contraction velocity of the diaphragm; PRV, Peak relaxation velocity of the diaphragm, VTI, Velocity-time integral.

The diaphragm ultrasound parameters in COPD Patients of different severity is shown in Table 3. The values of DT_insp, DTF, DE_DB decreased as the severity of COPD increased, conversely, DE_QB, DCV_QB, PCV, PRV and VTI increased with the severity of COPD($p < 0.05$).

Variables Associated with COPD

The correlation between diaphragm ultrasound parameters and pulmonary function is shown in Table 4. The results showed that DTF was positively correlated with FEV₁ predicted ($r=0.713$, $P=0.000$), DE_QB ($r=-0.740$ and -0.889), PCV ($r=-0.609$ and -0.778), PRV ($r=-0.686$ and -0.857) were negatively correlated with FEV₁/FVC and FEV₁ predicted ($P=0.000$).

Parameters Predictor of COPD

ROC curves with sensitivity, specificity, positive predictive value, negative predictive value to predict COPD were calculated (Table 5). DTF was positively correlated with FEV₁ predicted ($r=0.713$, $P=0.000$), DE_QB ($r=-0.740$ and -0.889), PCV ($r=-0.609$ and -0.778), PRV ($r=-0.686$ and -0.857) were negatively correlated with FEV₁/FVC and FEV₁ predicted ($P=0.000$). Meanwhile, DE_QB, DCV_QB, PCV and PRV exhibited superior performance in predicting

Table 3 Diaphragm Ultrasound Parameters in COPD Patients of Different Severity

Variable	GOLD 1(12)	GOLD 2(32)	GOLD 3(20)	GOLD 4(11)	F	P
B-mode_Thickness (cm)						
DT-exp	0.19±0.04	0.17±0.03	0.17±0.04	0.18±0.03	0.640	0.592
DT-insp	0.45±0.10	0.34±0.08	0.27±0.05	0.27±0.05	14.366	0.000
DTF	136.56±18.49	96.29±24.28	61.41±9.31	54.34±12.03	53.735	0.000
M-mode_Excursion						
DE-CB (cm)	1.43±0.13	1.65±0.20	2.26±0.33	2.58±0.38	59.510	0.000
Velocity-CB (cm/s)	1.09±0.17	1.56±0.43	2.11±0.71	2.34±0.71	15.783	0.000
DE-DB (cm)	7.00±1.13	5.32±0.81	4.52±1.08	4.20±0.76	22.845	0.002
Velocity-DB (cm/s)	2.08±0.56	2.69±0.70	2.79±0.84	2.63±1.04	2.377	0.077
TDI parameters						
PCV	1.63±0.47	2.66±0.47	3.56±0.84	4.83±1.89	27.863	0.000
PRV	1.30±0.33	2.73±0.48	4.51±1.01	5.20±1.56	57.938	0.000
VTI	1.62±0.45	2.30±0.47	2.75±0.70	2.58±0.69	10.591	0.000

Note: Data expressed as mean±standard deviation.

Abbreviations: DT-exp, Diaphragm thickness at the end of tidal expiration; DT-insp, Diaphragm thickness at the end of tidal inspiration; DTF, Diaphragm thickening fraction; DE, Diaphragm excursion; DCV, Diaphragmatic contraction velocity; QB, quiet breathing; DB, deep breathing; PCV, Peak contraction velocity of the diaphragm; PRV, Peak relaxation velocity of the diaphragm, VTI, Velocity-time integral.

Table 4 Correlation Between Diaphragm Ultrasound Parameters and Pulmonary Function

Parameters	FEV ₁ /FVC		FEV ₁ % predicted	
	r	P	r	P
DT_insp (cm)	0.270	0.001	0.387	0.000
DTF (%)	0.544	0.000	0.713	0.000
DE_QB (cm)	-0.740	0.000	-0.889	0.000
DCV_QB (cm/s)	-0.556	0.000	-0.669	0.000
DE_DB (cm)	0.314	0.000	0.515	0.000
PCV (cm/s)	-0.609	0.000	-0.778	0.000
PRV (cm/s)	-0.686	0.000	-0.857	0.000
VTI	-0.463	0.000	-0.566	0.000

Abbreviations: DT-insp, Diaphragm thickness at the end of tidal inspiration; DTF, Diaphragm thickening fraction; DE, Diaphragm excursion; DCV, Diaphragmatic contraction velocity; QB, quiet breathing; DB, deep breathing; PCV, Peak contraction velocity of the diaphragm; PRV, Peak relaxation velocity of the diaphragm, VTI, Velocity-time integral.

Table 5 The Value of Diaphragm Ultrasound Parameters for Predicting COPD

Parameters	AUC	95% CI	Cut-Off Values	Sensitivity(%)	Specificity(%)	PPV(%)	NPV(%)	P
DT_insp (cm)	0.653	0.571–0.729	≤0.34	66.67	60.00	62.5	64.3	0.0007
DTF (%)	0.757	0.680–0.823	≤85.19	57.33	98.67	97.7	69.2	<0.0001
DE_QB (cm)	0.906	0.847–0.947	>1.48	81.33	90.67	89.7	82.9	<0.0001
DCV_QB (cm/s)	0.833	0.763–0.889	>1.27	74.67	80.00	78.9	75.9	<0.0001
DE_DB (cm)	0.664	0.583–0.739	≤4.78	42.67	96.00	91.4	62.6	0.0003
PCV (cm/s)	0.859	0.792–0.910	>2.33	74.67	97.33	96.6	79.3	<0.0001
PRV (cm/s)	0.833	0.764–0.889	>2.41	76.00	100.00	100.0	80.6	<0.0001
VTI	0.747	0.670–0.815	>2.07	69.33	74.67	73.2	70.9	<0.001

Abbreviations: DT-insp, Diaphragm thickness at the end of tidal inspiration; DTF, Diaphragm thickening fraction; DE, Diaphragm excursion; DCV, Diaphragmatic contraction velocity; QB, quiet breathing; DB, deep breathing; PCV, Peak contraction velocity of the diaphragm; PRV, Peak relaxation velocity of the diaphragm; VTI, Velocity-time integral; PPV, Positive predictive value; NPV, Negative predictive value.

COPD, with AUC values of 0.906, 0.833, 0.859 and 0.833, respectively. DE_QB exhibited 81.33% sensitivity, while DTF, DE_QB, DE_DB, PCV and PRV showed high specificity (98.67%, 90.67%, 96.00%, 97.33% and 100%, respectively). Notably, PRV showed 100% positive predictive value.

Discussion

In COPD patients, prior research has documented alterations in diaphragmatic function compared to healthy individuals.¹³ This study observed that DT-insp was reduced in COPD patients relative to healthy controls and further diminished as the severity of COPD increased, a finding consistent with earlier studies.^{10,14} The underlying cause may involve sarcomere adaptation in muscle fibers that maintains static diaphragm thickness, along with compensatory hypertrophy due to overuse and hyperinflation associated with increasing COPD severity.¹⁵ DTF is more sensitive than diaphragm thickness measurement in reflecting diaphragm contraction, it was observed that DTF was lower in COPD patients compared with healthy subjects and varied according to disease severity. This could be attributed to the force-length relationship that restricts contractility.¹⁶

During quiet breathing, DE was higher in COPD patients than in healthy subjects, likely due to increased inspiratory effort resulting from pulmonary hyperinflation, which aligns with previous findings.^{17,18} Conversely, during deep breathing, DE was lower in COPD patients, primarily because of air trapping, Shiraishi et al confirmed this factor.¹⁹

TDI is a widely utilized ultrasound technique, using a low-pass filter to capture low-velocity, high-amplitude signals, provides comprehensive insights into regional and global myocardial systolic and diastolic function. Soilemezi et al were pioneers in applying TDI to evaluate diaphragm function.²⁰ This study utilized TDI indices to assess diaphragmatic contractile performance in COPD patients. Notably, PCV and PRV exhibited the highest area under the curve (AUC) values, indicating excellent sensitivity and specificity. PRV, in particular, showed high positive predictive value. Therefore, utilizing TDI enables the direct measurement of the diaphragmatic relaxation rate, indicating a promising application for this non-invasive parameter in quantifying diaphragmatic function in routine clinical practice and its utility in prognosis.

In this study, diaphragm ultrasound parameters were found to correlate with pulmonary function, DTF showed a positive correlation with FEV₁ predicted, while DE_QB, PCV exhibited negative correlations with both FEV₁/FVC and FEV₁ predicted, consistent with previous literature.^{21,22} It was concluded that a significant relationship between impaired respiratory mechanics and the severity of abnormal pulmonary function in COPD patients.

The limitation of this study include a limited sample size and the inability to conduct a fine stratified study. Additionally, influencing diaphragm activity, such as smoking, lifestyle, age, ethnic differences, were not statistically analyzed. In order to gain deeper insights into the diaphragm ultrasound parameters associated with COPD and their significance, we plan to conduct a comprehensive investigation through multi-center studies with larger sample volume.

In conclusion, diaphragm ultrasound parameters are effective means of evaluating diaphragmatic function in COPD patients, with changes correlating with the severity of COPD. These parameters also correlate with pulmonary function test results, making diaphragm ultrasound suitable as a routine monitoring tool for COPD patients. However, it is important to acknowledge certain limitations of this study. Firstly, the small patient cohort limits the establishment of robust diagnostic reference values and stratified analysis; Secondly, the study fails to explore the potential impact of other variables such as smoking, lifestyle, age, BMI, ethnic differences and comorbidity on COPD assessment.

Conclusion

Multimodal ultrasound imaging offers a sensitive approach for detecting diaphragmatic dysfunction in COPD patients. Diaphragm ultrasound parameters correlate with pulmonary function and COPD severity, indicating that these parameters can provide valuable insights into disease progression and management.

Data Sharing Statement

The validation dataset used and/or analyzed during the current study is available from the corresponding author upon reasonable request.

Funding

This study was supported by The Medical Discipline Construction Program of Shanghai Pudong New Area Health Commission (the Key Weak Disciplines Program) [grant number: PWZbr2022-05].

Disclosure

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Global Initiative for Chronic Obstructive Lung Disease (GOLD). Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease (2024 report). Available from: <https://goldcopd.org/2024-gold-report/>. Accessed March 2024.
2. F Y Wang ZYL, He WW, Chen RC, Chen RC. Annual research progress in chronic obstructive pulmonary disease 2024. *Zhonghua Jie He He Hu Xi Za Zhi*. 2025;48(1):60–65. doi:10.3760/cma.j.cn112147-20241011-00598
3. Bifan Z, Yanfang W, Jian M, Wen C, Luying Z. Disease burden of COPD in China: a systematic review. *Int J Chronic Obstructive Pulmonary Dis*. 2018;13:1353–1364. doi:10.2147/copd.s161555
4. Abdallah F, Anthony B, Adam O, et al. Diaphragm: pathophysiology and ultrasound imaging in neuromuscular disorders. *J Neuromusc Dis*. 2018;5(1):1–10. doi:10.3233/jnd-170276
5. Massimo Z, Massimiliano G, Speranza B, Luca C, Paolo B, Alberto Z. Assessment of diaphragmatic dysfunction in the critically ill patient with ultrasound: a systematic review. *Intensive Care Med*. 2016;43(1):29–38. doi:10.1007/s00134-016-4524-z
6. Aymeric Le N, François P, Marta L, et al. Diagnostic accuracy of diaphragm ultrasound to predict weaning outcome: a systematic review and meta-analysis. *Int J Nurs Stud*. 2021;117:103890. doi:10.1016/j.ijnurstu.2021.103890
7. Tom S, Samira F, Ewan CG. Assessing diaphragmatic function. *Respiratory Care*. 2020;65(6):807–819. doi:10.4187/respcare.07410
8. Ewan CG, Franco L, Michael ED, et al. Measuring diaphragm thickness with ultrasound in mechanically ventilated patients: feasibility, reproducibility and validity. *Intensive Care Med*. 2015;41(4):642–649. doi:10.1007/s00134-015-3687-3
9. Libertario Demi FW, Klersy C, De Silvestri A, Perrone T. New international guidelines and consensus on the use of lung ultrasound. *J Ultrasound Med*. 2023;42(2):309–344. doi:10.1002/jum.16088
10. Okura K, Iwakura M, Shibata K, et al. Diaphragm thickening assessed by ultrasonography is lower than healthy adults in patients with chronic obstructive pulmonary disease. *The Clinical Respiratory Journal*. 2020;14(6):521–526. doi:10.1111/crj.13161
11. Nuttapol R, Vilasinee M, Benjamas C, Jamsak T, Laurent B. Ultrasound evaluation of parasternal intercostal, diaphragm activity and their ratio in male patients with COPD. *Am J Respir Crit Care Med*. 2024. doi:10.1164/rccm.202310-1769le
12. Michael RB, Leili S, Eric JS, et al. B-mode ultrasound assessment of diaphragm structure and function in patients with COPD. *Chest*. 2014;146:680–685. doi:10.1378/chest.13-2306
13. Jaber SA, Tope O, Jithin KS, et al. Diagnostic and clinical values of non-cardiac ultrasound in COPD: a systematic review. *BMJ Open Resp Res*. 2020;7(1):e000717. doi:10.1136/bmjresp-2020-000717
14. Sanket J, Girija N, Abhishek N, Abhay U. Study of the diaphragm in chronic obstructive pulmonary disease using ultrasonography. *Lung India*. 2019;36(4):299–303. doi:10.4103/lungindia.lungindia_466_18
15. Sawsan BE. Impact of chronic obstructive pulmonary disease severity on diaphragm muscle thickness. *Egypt J Chest Dis Tuberculosis*. 2017;66(4):587–592. doi:10.1016/j.ejcdt.2017.08.002
16. Ceyhun T, Eylem TÛTÛN Y, Mustafa H, Suat K. Examination of diaphragm thickness, mobility and thickening fraction in individuals with COPD of different severity. *Turkish J Med Sci*. 2022;52:1288–1298. doi:10.55730/1300-0144.5435
17. Camilo C, Alain B, Jorge Hugo V, Luciano Z. Diaphragmatic mobility loss in subjects with moderate to very severe COPD may improve after in-patient pulmonary rehabilitation. *Respiratory Care*. 2018;63:1271–1280. doi:10.4187/respcare.06101
18. Magdalena R, Małgorzata P, Paweł L. Diaphragmatic mobility loss in subjects with moderate to very severe COPD may improve after in-patient pulmonary rehabilitation. *Respiratory Care*. 2021;66(2):354.1–354. doi:10.4187/respcare.08687
19. Masashi S, Yuji H, Ryuji S, et al. Diaphragmatic excursion correlates with exercise capacity and dynamic hyperinflation in COPD patients. *ERJ Open Res*. 2020;6(4):00589–2020. doi:10.1183/23120541.00589-2020
20. Eleni S, Savvoula S, Panagiota S, Dimitrios S, Matthew T, Dimitrios M. Tissue Doppler imaging of the diaphragm in healthy subjects and critically ill patients. *Am J Respir Crit Care Med*. 2020;202(7):1005–1012. doi:10.1164/rccm.201912-2341oc
21. Andrea S, Riccardo I, Linda T, Alessandro Di Marco B, Salvatore V, Giuseppe Maria C. Ultrasonographic assessment of the diaphragm in chronic obstructive pulmonary disease patients: relationships with pulmonary function and the influence of body composition - A pilot study. *Respiration*. 2014;87(5):364–371. doi:10.1159/000358564
22. Bianca S, Diego Condeso de A, Yves Raphael S, et al. Ultrasonography as a way of evaluating the diaphragm muscle in patients with chronic obstructive pulmonary disease. *Medicine*. 2024;103(38):e39795. doi:10.1097/md.00000000000039795

International Journal of Chronic Obstructive Pulmonary Disease

Dovepress
Taylor & Francis Group

Publish your work in this journal

The International Journal of COPD is an international, peer-reviewed journal of therapeutics and pharmacology focusing on concise rapid reporting of clinical studies and reviews in COPD. Special focus is given to the pathophysiological processes underlying the disease, intervention programs, patient focused education, and self management protocols. This journal is indexed on PubMed Central, MedLine and CAS. The manuscript management system is completely online and includes a very quick and fair peer-review system, which is all easy to use. Visit <http://www.dovepress.com/testimonials.php> to read real quotes from published authors.

Submit your manuscript here: <https://www.dovepress.com/international-journal-of-chronic-obstructive-pulmonary-disease-journal>