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Assessment of diaphragmatic thickness as a predictor for intubation in pneumonia patients

Elzahraa Wagdy Abdelfatah,[1] Salwa Hussein Abdelmoneim,[2] Hend Yahia Zakaria,[3] Fatmaalzahraa Saad Abdalrazik[2]

[1]Faculty of Medicine, Banha University; [2]Chest Diseases Department, Faculty of Medicine, Helwan University; [3]Critical Care Department, Faculty of Medicine, Helwan University, Egypt

Correspondence: Elzahraa Wagdy Abdelfatah, Faculty of Medicine, Banha University, Banha, 13511, Egypt.
Tel.: +201032286618. Fax: 0133227491. E-mail: Elzahraawagdy29@gmail.com

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Abstract

Pneumonia, one of the major contributors to morbidity and mortality globally, often leads to serious complications such as respiratory failure. Diaphragmatic dysfunction, detected through ultrasound, may predict the need for intubation in patients with pneumonia. This study aimed to evaluate the roles of diaphragmatic thickness fraction (DTF) and diaphragmatic excursion (DE) as predictors of intubation in pneumonia patients. This follow-up cohort study involved 53 participants diagnosed with pneumonia. Diaphragmatic ultrasonography was performed to measure DTF and DE within 24 hours of admission. The mean age of the patients was 51.8±20.4 years, with 66% being male. Diabetes mellitus (DM) ($p=0.000$) and hypertension (HTN) ($p=0.003$) were significantly associated with the need for intubation. DE was significantly correlated with intubation ($p=0.001$). At a cut-off of 2.9 cm, DE demonstrated 100% sensitivity and 56% specificity for predicting intubation. DTF exhibited 92% sensitivity and 60% specificity at a cut-off of 0.52, with a positive predictive value of 85% and a negative predictive value of 54%. Diaphragmatic parameters, particularly DE and DTF, are significant predictors of intubation in pneumonia patients. Comorbidities such as DM and HTN also play a critical role, underscoring the importance of early identification of high-risk patients for timely intervention.

Key words: diaphragmatic ultrasound, diaphragmatic excursion, diaphragmatic thickening fraction, pneumonia, intubation predictors.

Introduction

Pneumonia, an infectious condition that primarily affects the lung parenchyma, remains a significant global health concern due to its high contribution to morbidity and mortality. In 2016, it was identified as the deadliest infectious disease and the fourth leading cause of death, claiming approximately 3 million lives worldwide [1].

Pneumonia can be classified into community-acquired pneumonia (CAP), which is acquired outside a hospital setting, and hospital-acquired pneumonia (HAP), which develops more than 48 hours after hospital admission in non-intubated patients [2,3].

CAP can be caused by a variety of pathogens, most commonly bacteria or viruses, leading to inflammation of the air sacs in the lungs. The clinical presentation of CAP varies significantly among patients, ranging from mild to severe symptoms [2]. In contrast, HAP tends to affect patients who are already hospitalized, often complicating their clinical course [3].

To assist in managing CAP, the pneumonia severity index (PSI) is frequently used, as it has proven effective in risk stratification. It is endorsed by both the American Thoracic Society and the Infectious Diseases Society of America (IDSA). However, the complexity of the PSI score presents challenges for rapid calculation, limiting its use in emergency departments. In comparison, the CURB-65 score, favored by the British Thoracic Society and the National Institute for Health and Care Excellence (NICE) for its simplicity, has not been fully validated in terms of its capacity to guide clinical decision-making reliably [4].

The diaphragm, as the primary inspiratory muscle, plays a crucial role in respiration. Dysfunction in diaphragmatic function has been linked to severe CAP, infection, and sepsis, and is often indicative of organ failure. Such dysfunction is associated with prolonged intensive care unit (ICU) admissions and difficulties in weaning patients from mechanical ventilation [5].

Historically, diagnosing diaphragmatic dysfunction posed significant challenges, but with the advent of point-of-care ultrasonography, this process has been greatly simplified. Diaphragmatic function can now be assessed using two primary ultrasound techniques: diaphragmatic thickening fraction (DTF), which quantifies the change in diaphragmatic thickness between end-inspiration and end-expiration, and diaphragmatic excursion (DE), which measures the vertical movement of the diaphragm during the breathing cycle [6].

This study seeks to investigate whether diaphragmatic thickness specifically DTF and DE, in predicting the need for intubation in patients with pneumonia. By exploring whether these measurements can serve as reliable predictors, we hope to enhance early decision-making in the management of pneumonia and its complications.

Materials and Methods

Study design and population

This study is follow up cohort, study was done in Helwan University Hospitals on 53 pneumonia patients from July 2023 to July 2024, following approval from the Institutional Review Board of Helwan University and the Chest Department. (Approval No.: 91-2023). Written informed consent was obtained from all subjects in the study or their relatives.

Patient selection

The study included both male and female patients aged over 18 years who were diagnosed with pneumonia before the consideration of intubation. The exclusion criteria were as follows: patients who were already intubated, those requiring intubation upon initial presentation, patients with diaphragmatic anatomical malformations, and individuals with communication difficulties that prevented the accurate assessment of their condition.

All selected participants underwent a comprehensive evaluation, which included detailed history taking, clinical examination, general chest examination, laboratory evaluations (including arterial blood gases), and a CT chest scan upon admission.

Diaphragmatic ultrasonography

DUS was performed within 24 hours of patient presentation [7]. The ultrasound measurements were repeated for three consecutive respiratory cycles and averaged. The examination focused on the right hemidiaphragm, as the left hemidiaphragm is often obscured by gastric contents and the spleen, making it more difficult to assess. The DTF and DE measurements were collected for statistical analysis. DTF was estimated using a high-frequency ultrasound probe (13–6 MHz) positioned at the costophrenic angle of the right hemithorax, along the mid-axillary line, with the probe marker facing cephalad. The right hemithorax was chosen due to the liver's presence, which serves as an acoustic window, improving the accuracy of diaphragm measurements.

DTF Measurement: First, a low-frequency probe was used to identify the liver and pleural line during breathing. Afterward, the high-frequency probe was used to locate and center the zone of appositio the area where the diaphragm meets the pleural line. The diaphragm was then measured from its pleural layer to the peritoneal layer at both the end of inspiration and expiration to calculate the DTF.

The formula used was:

$$\mathbf{DTF} = \left(\frac{\mathbf{DTI - DTE}}{\mathbf{DTE}}\right) \times \mathbf{100}$$

DE Measurement: The movement of the diaphragm was evaluated using ultrasound imaging. The patient was positioned supine, and the ultrasound probe (a low-frequency curved transducer) was placed below the right ribcage between the mid-clavicular and anterior axillary lines (the right subcostal view). The probe was angled cranially in a sagittal plane to capture a cross-sectional image of the posterior diaphragm, with the liver enhancing the visibility of the diaphragm. The DE was measured as the distance traveled by the diaphragm during the breathing cycle.

Operational definitions

To ensure clarity in the study, the following operational definitions were established:

Intubation: the need for endotracheal intubation, which was the primary outcome of the study, was defined as the clinical decision to insert a breathing tube due to the patient's inability to maintain adequate oxygenation or ventilation. The decision for intubation was made by the attending physician based on clinical judgment, including factors such as respiratory distress, hypoxia, and hypercapnia. The intubation outcome was considered independent of the diaphragmatic parameters assessed in the study to avoid bias. Diaphragmatic measurements (DTF and DE) were used as predictors, not direct causes, of intubation.

Pneumonia diagnosis: pneumonia was diagnosed based on clinical symptoms, physical examination, and radiological findings, including chest X-ray and/or CT chest. The diagnosis had to be confirmed by a physician.

Diaphragmatic dysfunction: the assessment of diaphragmatic dysfunction was based on the DTF and DE measurements. A lower DTF or a reduced DE was considered indicative of diaphragmatic dysfunction, which may correlate with ahigher risk of respiratory failure and the need for intubation.

The clinical progress of all recruited patients was closely monitored until the study endpoints were reached, defined as either intubation or discharge from the hospital. Patients who required intubation were considered to have reached the primary outcome, and their DTF and DE values were analyzed in comparison to those who did not require intubation.

Sample size

Cochran formula is used to calculate the essential sample size for the required level of precision, confidence level and the estimated proportion of the attribute present in the population.

$n = Z^2 \ p \ q/e^2$

where

n is the sample size,

Z level of confidence according to the standard normal distribution (for a level of confidence of 95%, z = 1.96

e tolerated margin of error (10%)

p is the estimated prevalence of the disease

q is 1- p.

According to Sousa et al., 2018 reported incidences, the Prevalence of intubation associated pneumonia is calculated to be about 16%. So the estimated sample size according to equation is 53 patients. [8]

$n = 1.96^2 \quad 0.16 \quad 0 .84 / 0.1^2 \quad 53$ patients

Statistical methods

Data analysis was done utilizing SPSS software, version 20 (SPSS Inc., PASW Statistics for Windows, version 20, Chicago: SPSS Inc.). Qualitative data were presented as counts and percentages, whereas quantitative data were summarized utilizing the median (with minimum and maximum values) for non-normally distributed data and the mean ± standard deviation (SD) for normally distributed data. To evaluate differences for significance, the following tests were applied: the Chi-square test (χ^2) for differences and associations across qualitative variables, and the t-test for differences between independent quantitative groups. A p-value of less than 0.05 was considered statistically significant. The diagnostic performance of each test was assessed using the receiver operating characteristic (ROC) curve youden index analysis with an AUC above 50% indicating acceptable performance and a value closer to 100% representing optimal performance.

Results

The studied group mean age was 51.8 ± 20.4 years, with ages ranging from 18 to 83 years. More than half (66%) of the group were male. In terms of co-morbidities, 39.6% had hypertension (HTN), 32.1% had diabetes mellitus, 13.2% had neurological conditions, and 11.3% had a history of chest disease as 6% had COPD (chronic obstructive pulmonary disease) and 5% had bronchiectasis and asthma (Table 1).

There is a highly statistically significant association between diabetes mellitus and intubation (p = 0.000), as well as a statistically significant association between hypertension (HTN) (p= 0.003), smoking (p= 0.025), and intubation. No statistically significant association was found between previous chest disease and intubation (p= 0.317) (Table 2).

The study shows the following mean values and SD for vital signs: heart rate (HR) was 89.3 ± 8.2, temperature was 38.1 ± 1.3, systolic blood pressure (SBP) was 112.8 ± 18.1, diastolic blood pressure (DBP) was 73.3 ± 11.9, respiratory rate was 30.7 ± 5.4, oxygen saturation (SPO_2%) was 88.8 ± 9.6, and CURB-65 score was 2 ± 0.6.
For laboratory measures, the mean values and SD were as follows: hemoglobin (Hb) was 11.1 ± 1.2, total leukocyte count (TLC) was 12.9 ± 4.2, platelet count (PLT) was 411.7 ± 195.6, C-reactive protein (CRP) was 44.3 ± 25.8, sodium (Na) was 131.4 ± 4.4, potassium (K) was 4 ± 0.61, urea was 43.1 ± 28.4, creatinine was 1.9 ± 1.5, pH was 7.4 ± 0.06, carbon dioxide (CO_2) was 36.5 ± 3.9, and bicarbonate (HCO_3) was 22.5 ± 3.1 (Table 3).
TLC, CRP and DTF were significantly higher while PLT, K, urea, PH, HCO3, DE were significantly lower in intubation group than no intubation group (Table 4).
71.7% of the participants had CAP, while 28.3% had HAP, 47.2% were admitted to the ICU 24.5% required intubation (Table 5).
At a cutoff point of 2.9 cm, DE can significantly predict intubation (P value 0.001) at an [area under the curve (AUC) CI: 0.699-0.932] of 0.815, with a sensitivity of 100% and a specificity of 56%, [positive predictive value (PPV)] was 92%, and the [negative predictive value (NPV)] was 45% (Table 6).
Additionally, at a cutoff point of 0.52, DTF can significantly predict intubation (P value 0.032) at an [AUC, CI: 0.533- 0.867] of 0.7, with a sensitivity of 92% and a specificity of 60%, PPV of 85%, and the NPV of 54% (Figure 1 and Table 7).

Discussion

The investigated group mean age was 51.8 ± 20.4 years, ranging from 18 to 83 years. Our study found that 39.6% of participants had hypertension as a co-morbidity with a statistically significant association between HTN and risk for intubation (p=0.003) [9].
Our study found that 32.1% of participants had diabetes mellitus as a co-morbidity and there was highly statistically significant association between DM and risk for intubation (p=0.000) [10].
Our research revealed that the CURB-65 score for patients who were intubated was 2.2 ± 0.8, In line with our finding, a study was conducted by some authors to assess the predictive performance of CURB-65 for the proximal endpoint of receipt of critical care intervention (CCI) in Emergency Department (ED) patients admitted with community acquired pneumonia. Researchers carried out a retrospective review of electronic health records at a single tertiary care facility, examining patients from the emergency department who were admitted as inpatients with pneumonia as their primary diagnosis from 2010 to 2014. Of the 2,322 patients

in the cohort, 1,159 (49.9%) had a CURB-65 score of 0–1, 826 (35.6%) had a score of 2 and 337 (14.5%) patients had a score of 3. those patients with a CURB-65 score of 2 and those with a score of 3–5 were more likely to receive CCIs. Amongst patients receiving CCIs, central venous line (n=200, 61.9%), endotracheal intubation (169, 49.3%) was the most common. Of patients with a The ICU admits individuals with a CURB-65 score between 0 and 1, 36 (19.9%) underwent endotracheal intubation [11].

Our research found that the DE was 2.8 ± 1.6 cm. There was a statistically significant association between DE and intubation (p=0.002) with cut off point 2.9 cm with [AUC, CI: 0.699- 0.932] 0.815, DE had a sensitivity 100% and specificity 56% in prediction of intubation among the studied group with PPV of 92% and NPV of 45%.

In agreement with our findings, a study was led by Gürün Kaya et al. aimed to assess the impact of DE measured by ultrasound on the prognosis of severe pneumonia in critical care patients. They found DE was lower in patients who required invasive mechanical ventilation (24.90 ± 10.93 vs 34.26 ± 11.70, p= 0.017) [12].

Our study found that there was a statistically significant association between DTF and intubation (p= 0.048) with cut off point 0.52 with [AUC, CI: 0.533- 0.867] 0.7, DTF had a sensitivity 92% and specificity 60% in prediction of intubation among the studied group with PPV of 85% and NPV of 54%.

This aligns with a case series study by Hache-Marliere et al. which aimed to estimate the effectiveness of diaphragm ultrasound in predicting respiratory failure across participants with SARS-CoV-2. The investigation focused on changes in respiratory status in patients utilizing variant types of oxygen therapy, excluding those on Non-Invasive Positive Pressure Ventilation (NIPPV) or intubated. They conducted bedside diaphragmatic ultrasound evaluations, specifically measuring DTF, on individuals receiving various non-invasive oxygen therapies, such as High-Flow Nasal Cannula (HFNC) and Non-Rebreather Masks (NRB), due to hypoxic respiratory failure from COVID-19 pneumonia. The findings revealed a correlation between changes in DTF and the deterioration or improvement of respiratory failure, revealing that a decline in DTF is followed by a worsening of the patient's respiratory condition [13].

In contrast to our study, a study carried out by Chu et al. aimed to estimate the DUS accuracy in predicting respiratory failure in individuals with CAP, as well as its feasibility for usage in ED. The investigations found that at a cut-off point of 23.95%, DTF demonstrated an 80% accuracy rate in predicting the respiratory failure onset in CAP patients, with a sensitivity of 69.23% and a specificity of 83.78%. Additionally, the high NPV of 88.57% and a negative likelihood ratio of 0.3672 reveal that individuals with a DTF greater than 23.95% are highly unlikely to experience respiratory failure.

Yet, the current study has some limitations such as the small sample size and recruitment of the cases from a single center. Also, the short follow up duration of the cases. Longer duration can allow for better assessment of the complications.

Conclusions

Diaphragmatic parameters, particularly DE and DTF, are significant predictors of intubation in pneumonia patients. Comorbidities like diabetes and hypertension also play a key role, highlighting the need for early identification of high-risk patients to ensure timely intervention.

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Table 1. Some demographic data and co-morbidities among the studied group.

Variable	N (53)	% (100)
Age (years): **Mean ± SD** **Median** **Range**	51.8± 20.4 53 17-83	
Sex: **Male** **Female**	 35 18	 66 34
Smoking	23	43.4
Conscious	53	100
DM	17	32.1
HTN	21	39.6
Cardiac comorbidity	5	9.4
Renal comorbidity	4	7.5
Neural comorbidity	7	13.2
Previous chest disease	6	11.3

Hb, hemoglobin; DM, diabetes mellitus; HTN, hypertension.

Table 2. Comparison between intubation and co-morbidities among the studied group.

Variable	Intubation				χ 2	P-value
	No (N=40)		Yes (N=13)			
	N	%	N	%		
DM: **No** **Yes**	 33 7	 82.5 17.5	 3 10	 23.1 76.9	Fisher	**0.000** *
HTN: **No** **Yes**	 29 11	 72.5 27.5	 3 10	 23.1 76.9	Fisher	**0.003** *
Smoking: **No** **Yes**	 19 21	 47.5 52.2	 11 2	 84.6 15.4	Fisher	**0.025** *
previous chest disease: **No** **Yes**	 34 6	 85 15	 13 0	 100 0	Fisher	0.317

*significant as p less than 0.05. Hb, hemoglobin; DM, diabetes mellitus; HTN, hypertension

Table 3. Laboratory measures and vital signs among the studied group

Variable	Mean ± SD	Range
HR	89.3 ± 8.2	72-112
Temperature	38.1 ± 1.3	36.8-39.5
SBP	112.8 ± 18.1	90-180
DBP	73.3 ± 11.9	55-120
RR	30.7 ± 5.4	19-40
SPO_2%	88.8 ± 9.6	65-99
Curb 65	2.5± 0.5 (Median: 2.5)	2-3
Hb	11.1 ± 1.2	7.5-13.9
TLC	12.9 ± 4.2	1.2-25
PLT	411.7 ± 195.6	138-965
CRP	44.3 ± 25.8	6-96
Na	131.4 ± 4.4	123-138
K	4 ± 0.61	2.4-5.5
Urea	43.1 ± 28.4	24-158
Creatinine	1.9 ± 1.5	0.68-9.7
PH	7.4 ± 0.06	7.23-7.48
CO_2	36.5 ± 3.9	25-49
HCO_3	22.5 ± 3.1	25-49

HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; TLC, total leukocytic count; PLT, platelet count test; CRP, C-reactive protein; Na, sodium; K, potassium.

Table 4. Comparison between intubation, diaphragmatic measures, and laboratory investigations in the studied group.

Variable	Intubation		t-test	P-value
	No (N,40)	Yes (N,13)		
Hb: **Mean ± SD** **Range**	11.5 ±1.4 7.5-13.9	11.1 ±1.3 9-13	1.1	0.287
TLC: **Mean ± SD** **Range**	12.3 ±3.3 7.7-25	15.1 ±5.1 1.2-25	-2.2	**0.030***
PLT: **Mean ± SD** **Median** **Range**	450 ±208.1 381 139-965	293.5 ±62.2 295 185-379	2.6 #	**0.011***
CRP: **Mean ± SD** **Median** **Range**	37.6 ±22 36 6-96	64.6 ±26.6 48 24-96	-3.6 #	**0.001***
Na: **Mean ± SD** **Range**	130.9 ±4.5 123-138	132.8 ±4.1 124-137	1.4	0.176
K **Mean ± SD** **Range**	4.1 ±0.6 2.4-5.5	3.7 ±0.39 3-4.2	2.1	**0.037***
Urea: **Mean ± SD** **Median** **Range**	45.5 ±37.7 42 24-158	35.9 ±13 34 24-62	1.04 #	**0.039***
Creatinine: **Mean ± SD** **Median** **Range**	1.6 ±2.2 1 0.86-9.7	0.95 ±0.15 0.9 0.7-1.2	1.1 #	0.260
PH: **Mean ± SD** **Range**	7.4 ±0.04 7.2-7.5	7.3 ±0.07 7.2-7.5	3.2	**0.002***
CO_2 **Mean ± SD** **Range**	36.9 ±4.2 25-49	35.1 ±2.3 30-39	1.5	0.132
HCO_3: **Mean ± SD** **Range**	23.1 ±2.4 17.5-29	20.6 ±4.1 14.5-26.2	2.6	**0.010***
DE (cm): **Mean ± SD** **Range**	3.2 ±1.5 0.13-7	1.6 ±0.5 0.86-2.7	3.3	**0.002***
DTF (%): **Mean ± SD** **Median** **Range**	55 ±29 46 15-13.7	74 ±3 59 18-11.2	-19 #	**0.048***

#Man Whitney; *significant as p less than 0.05; Hb, hemoglobin; TLC, total leukocytic count; PLT, platelet count test; CRP, C-reactive protein; Na, sodium; K, potassium; DTF, diaphragmatic thickness fraction; DE, diaphragmatic excursion.

Table 5. Intubation, ICU admission, CAP & HAP among the studied group.

Variable	N (53)	% (100)
Intubation	13	24.5
ICU admission	25	47.2
CAP	38	71.7
HAP	15	28.3

Data are presented as number (%). ICU, intensive care unit; CAP, community-acquired pneumonia; HAP, hospital-acquired pneumonia.

Table 6. Validity of DE in prediction of intubation studied groups.

Variable	DE
AUC	0.815
Cutoff point	2.9
P-value	0.001
Sensitivity	100%
Specificity	56%
PPV	92%
NPV	45%

CI: (0.699-0.932)

Table 7. Validity of DTF in prediction of intubation studied groups.

Variable	DTF
AUC	0.7
Cutoff point	0.52
P-value	0.032
Sensitivity	92%
Specificity	60%
PPV	85%
NPV	54%

CI: (0.533- 0.867)

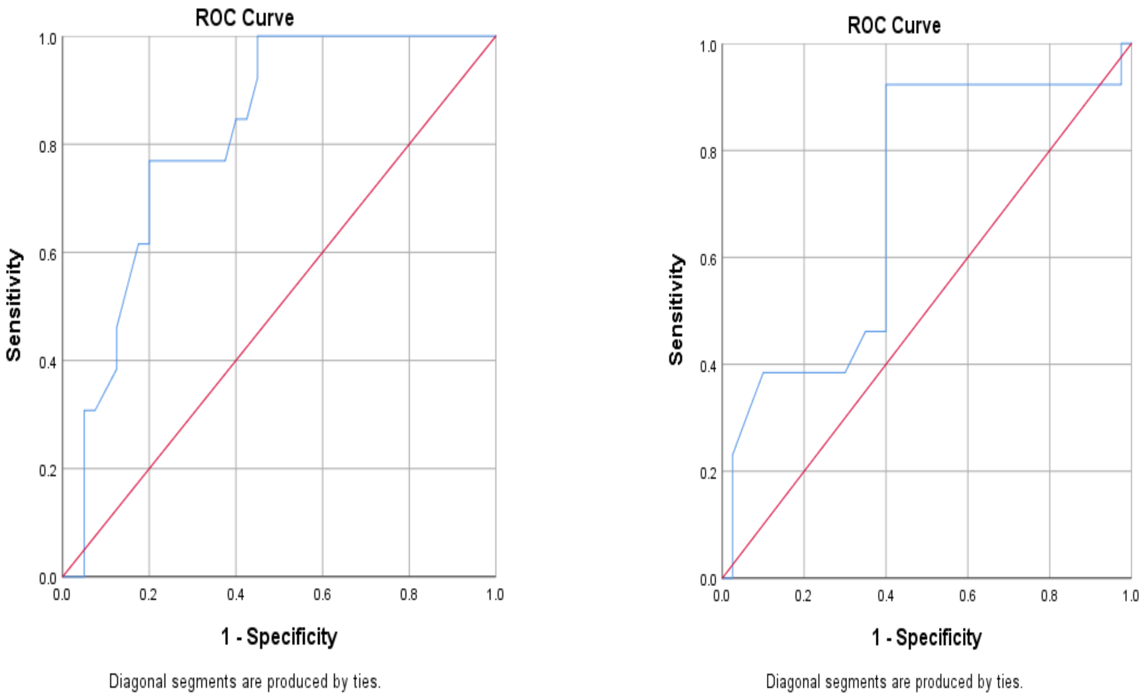

Figure 1. ROC curve for validity of DE (A) and DTF (B) in prediction of intubation among the studied groups.