Meeting report

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ABSTRACT

Every year, the Accademia di Ecografia Toracia (AdET), an Italian association focused on highlighting the scientific relevance of thoracic ultrasound (TUS) in clinical practice, presents the projects of its researchers from across Italy and beyond, in a National Congress where the results from AdET projects are shared and debated. Hereby we report the abstracts of the works submitted for publication.

Key words: Thoracic ultrasound, lung ultrasound, pleura, point of care ultrasound

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Effects of Tezepelumab on diaphragmatic workload and lung function in patients with severe asthma: a case series

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Introduction: Tezepelumab is a fully human monoclonal antibody that ligates TSLP, efficacious in the treatment of severe asthma. Its efficacy and safety were documented by different trials, as NAVIGATOR, SOURCE, DESTINATION, CASCADE and PATHWAY. However, there are not real-life studies about the improvement of lung function, symptoms, and diaphragmatic workload by ultrasound.
Objects: In this case series we have evaluated baseline lung function and diaphragmatic ultrasound values during triple inhaled therapy, and after one month of add-on biological therapy with Tezepelumab.
Methods: The initial lung function values were suggestive of obstruction, with an ACT score less than 20. Right diaphragmatic ultrasound evaluations were performed during seated and lying down position.
Results: After a month of add-on biological therapy with Tezepelumab, it was detected improvement of all lung function test values, and ACT score, becoming higher than 20. Particularly, FEV_1 changed in the first patient from 1.28 L (59%) to 1.67 L (77%), in the second one from 1.95% (60%) to 2.23 L (69%) and in the third one from 2.25L (80%) to 2.92 L (104%). FEF_{25-75} improved, from 0.92 L/s (49%) to 1.77 L/s (95%) in the first patient, from 0.77 L/s (29%) to 1.44 L/s (54%) in the second one and from 0.84 L/s (41%) to 1.96 L/s (96%) in the third one. About right diaphragmatic ultrasound, it was detected normalization of the parameters evaluated. In fact, TF changed in the first patient from 57.14% to 33.33%, in the second one from 44.00% to 30.76% and in the third one from 66.00% to 30.76%. Tidal volume excursion improved, from 2.71 cm to 2.48 cm in the first patient, from 3.11 cm to 2.23 cm in the second one and from 4.44 cm to 1.45 cm in the third one. Tidal volume inspiratory velocity changed from 2.9 cm/s to 2.3 cm/s in the first patient, from 2.8 cm/s to 2.7 cm/s in the second one and from 2.8 cm/s to 1.4 cm/s in the third one. These results could be explained by severe asthma pathogenesis. Tezepelumab causes reduction of T2 inflammatory marker levels and consequently reduction of dynamical hyperinflation, giving explanation for spirometric improvement and a potential explanation for the right diaphragmatic amelioration detected after one month of its use.
Conclusions: This case series underline for the first time a reduction of right diaphragmatic effort valuated by ultrasound, associated with lung function ameliorations after one month of add-on biological therapy with Tezepelumab.

Learning thoracic ultrasound: Evidence of rapid skill acquisition through a four-day intensive course

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Background: Thoracic ultrasound (TUS) has been emerging in last years as a valuable bedside tool in routine clinical practice. It represents a low-cost, easily accessible, and non-invasive imaging technique that can be performed directly at the patient's bedside. At the Fondazione Policlinico Universitario A. Gemelli IRCCS in Rome, an intensive 4-day course is organized by certified instructors (Level 3 according to BTS guidelines), covering all the main topics related to TUS. The program is subdivided into theoretical and practical sessions: during the first two days, participants attend frontal lectures delivered by field experts, while the last two days are dedicated to hands-on sessions performed on healthy volunteers, patients, standardized simulated patients and simulators, using ultrasound machines made available to trainees under the supervision of qualified tutors.
Objectives: Our primary endpoint is to evaluate the real effectiveness of this intensive course in improving participants' competence, with the goal of enabling them to independently perform and interpret thoracic ultrasound examinations, achieving Level 2B proficiency according to BTS standards. Methods: To objectively assess the participants' learning progress, a 10-item multiple-choice questionnaire (MCQs) is administered at the beginning and at the end of the course, after all the theoretical and practical modules.
Results: Correct mean answers provided before the course were 124.2 ± 54.2 (48%) of the total, rising to 199.8 ± 36.8 (77%) after with an overall mean improvement of 84%. Total answers provided rose from 257 ± 1.5 to 259 ± 2.7 in mean. Wilcoxon signed-rank p for correct answers before and after was 0.00195, while for total answers given p was equal to 0.0435. Cronbach's alpha test for internal consistency is 0.59 (CI -0.294 - 0.952) for answers before the course and 0.76 (CI 0.24 - 0.97) for answers post-course.
Conclusions: These results demonstrate a marked improvement in participant's theoretical knowledge and practical understanding of TUS. Our data suggests that an intensive four-day training course is sufficient to achieve a solid level of autonomy in performing and interpreting TUS examinations. TUS is an expanding field with growing potential, especially for young physicians pursuing advanced competence in respiratory medicine.

Impulse oscillometry in pulmonary emphysema – preliminary results from the Study "Assessment of pulmonary EmphySema: the Clinical-ULtrasonographic APproach to chronIc Obstructive pulmonary disease" - ESCULAPIO Trial"

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Background: Impulse oscillometry (IOS) is a non-invasive technique useful for assessing mechanical features of the respiratory system, by the application of a vibration throughout a mouthpiece. IOS measures the resistance of the airways and tissues to flow (Rrs) and the elastance (stiffness) of the lung parenchyma and chest wall in response to changes in volume (encompassed in reactance, Xrs). In patients with pulmonary emphysema these data give us the opportunity to evaluate if the structural changes in the bronchioloalveolar architecture are affecting the pulmonary function. Essentially, IOS provides complementary information to conventional spirometry, in a simply, effort-independent way, which could be crucial in some specific population groups, such as babies, elderly people, pluri-comorbidity patients. However, its application in clinical practice remains limited, because of heterogeneous results showed in different studies and the need to increase the knowledge about this relatively new respiratory functional test.
Methods: ESCULAPIO Trial is an ongoing national, multi-center, prospective, interventional study involving adult patients underwent chest CT scan with evidence of panlobular and/or paraseptal emphysema. For each par-

ticipant, impulse oscillometry and ultrasound parameters are collected, along with relevant clinical and anamnestic data.

Objectives: This study aims to evaluate the usefulness of impulse oscillometry in characterizing respiratory functional patterns in patients affected by paraseptal and/or panlobular emphysema, and to explore its correlation with ultrasound images (from both clinical and research scanners) and HRCT findings.

Study Status and Results: The recruitment phase is currently ongoing. R5Hz [kPa/(L/sec)] and X5Hz [kPa/(L/sec)] are the two oscillometric indices used to distinguish central airway obstruction (R5Hz increased/X5Hz normal) from peripheral airway obstruction (R5Hz normal/X5Hz reduced). If R5Hz was increased while X5Hz was reduced, mixed airway obstruction (central and peripheral) was identified. One hundred and forty-six patients (101 males) with evidence of paraseptal or panlobular emphysema have been enrolled. Median age was 69years [IQR=75-63], median height was 168cm [IQR=174-153], median weight was 73kg [IQR=82- 65]. Median R5Hz was 0.36 kPa/(L/sec) [IQR=0.48-0.28], 106% of predicted value [IQR=142-87], with median z-score of 0.23 [IQR=1.39-(-0.36)]. Median X5Hz was -0.11 kPa/(L/sec) [IQR=-0.06-(-0.15)], 273% of predicted value [IQR=520- 135], with median z-score of -0.53 [IQR=-0.23-(-0.95)]. Resonant frequency (Fres), the frequency at which the inertial properties of airway and the capacitance of lung periphery are equal, i.e., the frequency at which total reactance is zero, was used to separate low frequencies where capacitance component dominates from high frequencies where the inertial component takes over. Median Fres was 19Hz [IQR=24-13], whereas the normal value of in adults is 7-12 Hz. **Conclusions:** The ESCULAPIO study hopes to highlight the relevance of ultrasound imaging and impulse oscillometry in the evaluation and follow-up of COPD patients, to contribute to defining the clinical role of impulse oscillometry as a complementary tool in the assessment of respiratory function, with potential implications for the early diagnosis and monitoring of pulmonary diseases. The possibility to evaluate the grade of the emphysema involvement through LUS and IOS can give physicians quantitative analysis through non-invasive tools for the diagnosis and the follow-up of patients affected by panlobular and/or paraseptal emphysema. IOS can intercept the presence of peripheral airway obstruction without effort in a wide cohort of patients with pulmonary emphysema.

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Assessment of pulmonary EmphySema: the Clinical-ULtrasonographic APproach to chronIc Obstructive pulmonary disease - ESCULAPIO Trial: the protocol

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Background: Over the past 30 years, lung ultrasound has played a fundamental role in the evaluation of pleural diseases, pulmonary consolidations, and as a guidance tool for interventional procedures. However, limited attention has been given to the study of pulmonary emphysema, despite its high prevalence among patients with respiratory diseases. Pulmonary emphysema is characterized by a reduction in lung parenchymal density and an excessive amount of trapped air, resulting in alveolar wall destruction and damage to the interlobular septa. This leads to dilation and confluence of peripheral airspaces, with the formation of large subpleural air-filled bullae. Pulmonary emphysema is a pathology that occurs mostly in the peripheral portion of the lungs, so ideally explorable through LUS. From an ultrasonographic perspective, the lung increasingly resembles air, making its evaluation challenging. The interactions between ultrasound waves and hyperinflated parenchyma is characterized by the presence of horizontal artifacts and a qualitative reduction in lung sliding, depending on the grade of emphysema. Studying the physical char-

acteristics of the LUS image could be instrumental to overcome the qualitative evaluation of paraseptal and panlobular emphysema. The study aims to identify correlations between data obtained from lung ultrasound, with a quantitative approach to the US image, and tomographic imaging in patients with panlobular or paraseptal emphysema, with functional assessment completed through respiratory oscillometry.
Methods: We are enrolling 1,600 patients with panlobular and/or paraseptal emphysema, who have already undergone CT scan from Rome and Naples. Participants undergo lung ultrasound evaluation using a clinical scanner and a research platform, capable of obtaining LUS frames at different frequencies, employing commercially available linear transducers. All examinations are performed with the patients in supine position, consistent with the standard position used for chest CT scans. In addition, to complete the functional assessment, participants also undergo respiratory oscillometry. To correlate LUS artefactual patterns with peripheral parenchymal change evaluated by chest HRCT, all CT findings are analysed by an image processing platform designed to provide completely automatic visualization and qualification of areas with abnormal CT tissue density indicative of emphysema and air trapping. Patients enrolled in the study are recruited through three paths: 1. COPD patients, both outpatients in stable condition and in patients with acute exacerbation, followed by the Pulmonology Unit and showing HRCT evidence of paraseptal and/or panlobular emphysema; 2. Subjects participating in the lung cancer screening program; 3. Patients with suspected or confirmed lung cancer, managed in all medical units involved in the project. **Conclusions:** The role of lung ultrasound is becoming increasingly important in supporting clinical practice, particularly for pulmonologists. Nevertheless, CT scanning remains the gold standard for the assessment of pulmonary parenchyma, as ultrasound is currently limited to the evaluation of peripheral lung regions. This is why the ESCULAPIO study aims to integrate ultrasound data with CT imaging, to early intercept lung damage and provide a quantitative map of the pulmonary emphysema. This study highlights the advantages of lung ultrasound as a non-invasive, radiation-free, portable, and bedside-available imaging modality. These features allow for the early diagnosis and treatment of conditions such as emphysema, which are highly prevalent among patients with respiratory diseases.

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Novel Quantitative Lung Ultrasound Spectroscopy Approach for Lung Diseases Classification – Results from SAURON study [NCT06068647]

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Background: The development of ultrasound (US) for exploring lung pathologies is not supported by a strong knowledge of the physical mechanisms that underlie ultrasonographic lung artifacts. The main question to answer is about the correlations between thoracic ultrasonographic patterns and peripheral parenchymal changes in patients affected with variable degree of different diseases. The dependence on frequency of US artifacts can be instrumental to provide us with diagnostic information on lung pathologies. In SAURON Study [NCT06068647], we explored the use of a quantitative lung US spectroscopy approach to differentiate three different pulmonary diseases: acute exacerbation of pulmonary emphysema (AECOPD), pulmonary fibrosis (PF) and acute exacerbation of pulmonary fibrosis (AEPF).
Methods: The study introduced a novel quantitative multi-frequency analysis of three regions of the lung US image: pre-pleura, pleura and post-pleura. The study also included a novel semi-automatic algorithm for the detection of the pleural landmark to divide the three regions. We analyzed the intensity and frequency trend of the three regions of the image. We investigated patients affected by PF, AEPF and AECOPD. The diagnoses derived from chest CT scan. We acquired radiofrequency multifrequency data with the ULA-OP research scanner, connected to a LA523 (Esaote, Florence, Italy) linear probe (192 elements, 245- μm pitch). Each frame was manually segmented to identify the pleural landmark, then using a semi-automatic algorithm, each frame was divided into three regions: pre-pleura, pleura, and post-pleura. For each region, total intensity (ITotn),

center frequency (NFn) and bandwidth (BWn) were analyzed.

Results: The population was divided into three subgroups of patients based on the disease: 12 patients with AEPF, 20 patients with PF and 20 patients with AECOPD. In total, 8965 frames were segmented into the three US regions of interest. Univariate and multivariate analysis showed statistically significant results to differentiate AEPF from PF and AECOPD. To evaluate the potential association of these features and the probability of belonging to the AEPF group a multinomial logistic regression was performed. The analysis indicated that higher values of ITot1 and ITot3 were associated with a lower probability of belonging to PF and AECOPD compared to AEPF, whereas higher values of ITot2 were associated with a greater possibility of belonging to PF and AECOPD. These results suggest a systematic relationship between ITotn and the probability to belong to AEPF.

Conclusions: In this study, we proposed a method to reduce the limitations (subjectivity and poor reproducibility) of traditional qualitative and semi-quantitative lung US analysis. We explored whether the frequency trend of Itot1, Itot2 and Itot3 were significant in differentiating patients affected by AEPF rather than PF and AECOPD. Quantitative analysis represents a tool that can help physicians in the differential diagnosis with more accuracy. Further studies are needed to standardize and validate the quantifying model of lung US analysis, and to increase the population under examination. Furthermore, it could be interesting to evaluate the correlation between quantifiable US parameters, degree of pathological lung involvement and clinical data, in order to better integrate LUS in clinical practice.

Lung Ultrasound - Pulmonary Infarction (LUS-PI)

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Introduction: Pulmonary infarction (PI) is a frequently underdiagnosed condition that may complicate the clinical course of pulmonary embolism (PE). While computed tomography pulmonary angiography (CTPA) remains the gold standard for the diagnosis of PI, lung ultrasound (LUS) is emerging as a valuable, non-invasive and radiation-free tool for both detection and follow-up.

Case report: A 23-year-old woman presented to the Emergency Department (ED) in October 2023 with right hypochondrium pain and fever. She was initially discharged with a diagnosis of "suspected acute pyelonephritis" and antibiotic therapy. Persistent fever and the onset of pleuritic chest pain led her to a second ED visit. A chest X-ray revealed a small right basal diaphragmatic "pinching" with blunting of the right costophrenic angle, while abdominal ultrasound was unremarkable. Arterial blood gas analysis showed respiratory alkalosis without respiratory failure. Laboratory tests revealed mild leukocytosis, and D-dimer was markedly elevated.

Pulmonary embolism and pulmonary infarction in the right lower lung lobe were detected by CTPA. The patient was admitted to our Pulmonary Unit and enrolled in the LUS-PI prospective study, designed to assess the evolution of pulmonary infarction by ultrasound.

Serial LUS examinations were performed at baseline (blinded to CTPA findings), 5 days, 1 month, 3 months, and 1 year, by the same operators. Ultrasound findings obtained included long- and short-axis diameters, lesion shape, and the right-to-left ventricular (RV/LV) ratio. After discharge, the patient was followed in the outpatient clinic; anticoagulation therapy was discontinued after 3 months.

The pulmonary infarction initially presented as a wedge-shaped peripheral consolidation, which progressively evolved into an elongated over the first 3 months, with a significant reduction of the short-axis diameter. Unexpectedly, at the 1-year follow-up, the lesion had almost doubled in size, suggesting a late remodeling process. Further investigations are now planned.

Conclusions: Lung ultrasound may be a simple, unexpensive, and radiation-free tool that can effectively support both the diagnosis and especially the follow-up of pulmonary infarction. In this case, LUS provided dynamic, real-time insights into the morphological evolution of PI, an aspect often overlooked in traditional imaging follow-up.

References

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The 'Echo' of COVID-19: Two Case Reports in the Very-Long-Term Follow-Up

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Introduction: Lung ultrasound (LUS) is an increasingly used tool in daily clinical practice, due to its ease of use, portability (allowing bedside examination), repeatability, absence of ionizing radiation and good correlation with traditional radiologic findings. During the acute phase of the SARS-CoV-2 pandemic, LUS proved to be a valuable diagnostic and monitoring modality. Since then, several studies have confirmed its utility in monitoring medium- and long-term pulmonary sequelae. We present the clinical cases of two patients hospitalised for bilateral COVID-19 pneumonia in 2020, followed after discharge at the Pulmonology Unit of the Pisa University Hospital and re-evaluated five years later as part of the project "Very-long-term COVID-19 respiratory outcomes: clinical and molecular profiling of patients in different phases of the pandemic" (Progetti di Rilevante Interesse Nazionale-PRIN, bando 2022, Prot. 2022FJK39Z, Pisa University).
Case report: An 82-year-old man with no comorbidities was admitted in April 2020 for bilateral COVID-19 pneumonia and treated with oxygen and antiviral therapy. After discharge, he entered in a structured follow-up program including pulmonary function tests (PFTs), and single-breath carbon monoxide diffusing capacity (DL_{CO}), LUS, and chest computer tomography (CT) at 3, 12, and 24 months. At the 3-month evaluation, the patient was asymptomatic with normal PFTs and DL_{CO}. Concurrent LUS showed resolution of consolidations, a few isolated vertical artifacts, and minimal pleural irregularities, consistent with chest CT findings. At the 5-year follow-up, 59 months after acute COVID-19 pneumonia), clinical, PFTs and DL_{CO} evaluation remained normal, and the absence of pathological ultrasound findings confirmed complete recovery, in agreement with a last chest CT (performed at 50 months after acute COVID-19 pneumonia for unrelated reasons). A 75-year-old man with myelofibrosis, hospitalized for bone marrow transplantation in February 2020 contracted SARS-CoV-2 infection, which led to bilateral pneumonia requiring oxygen therapy and infusion of hyperimmune plasma. Follow-up evaluations at 3, 12, and 24 months showed, with persistent dyspnoea, restrictive ventilatory pattern, progressive DL_{CO} decline, and incomplete radiological resolution. LUS at 3 months revealed numerous vertical artifacts, diffuse pleural line abnormalities, without signs of consolidation or pleural effusion. These persistent abnormalities led to referral to the interstitial lung diseases (ILDs) clinic. In February 2024, a multidisciplinary diagnosis of post-COVID fibrosing ILD was made. Antifibrotic therapy with nintedanib was started but about 1 month later discontinued due to intolerance. At the latest reassessment in March 2025, 58 months after acute COVID-19 pneumonia), both clinical, functional and LUS evaluations confirmed a persistent interstitial
pattern, mainly involving both posterior mid-basal pulmonary regions, in agreement with chest CT findings and ongoing symptoms.
Conclusions: In both cases, LUS proved to be a reliable, reproducible, and radiologically consistent tool for monitoring post-COVID-19 pulmonary evolution. In the first case, it confirmed full resolution of the acute lung injury; in the second case, it contributed to the early identification of post-infectious fibrosing ILD, confirmed by chest CT and multidisciplinary discussion. LUS remains a valuable, accessible and promising imaging modality in the follow-up of ILDs, including post-COVID-19 Integrating lung ultrasound (LUS) into structured monitoring programs may enhance early detection and long-term disease management, especially in vulnerable or high-risk populations. Nonetheless, further prospective studies are required to more accurately determine its sensitivity, specificity, and potential limitations in this setting.

Serendipity of Lung Ultrasound in Clinical Practice

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Background: Lung ultrasound (LUS) has emerged as an essential extension of the pulmonary physical examination, o;ering a dynamic and bedside evaluation that can guide clinical decisionmaking not only in emergency but also in outpatient settings. We report a case in which LUS performed during the first ambulatory assessment

contributed to raising diagnostic suspicion, ultimately leading to an early diagnosis of small-cell lung carcinoma (SCLC).

Case presentation: A 79-year-old male, former heavy smoker (65 pack/years) with a history of chronic kidney disease, previous myocardial infarction, type 2 diabetes mellitus, and systemic hypertension presented at outpatient visit with progressive dyspnoea and one-month-lasting productive cough, despite antibiotic and corticosteroid therapy. Physical examination revealed additional bilateral breath sounds with scattered inspiratory and expiratory wheezes and coarse crackels. No peripheral oedema was observed; Bauer's sign was positive on the left leg. Arterial blood gas analysis excluded respiratory failure. Chest radiography was performed for further investigation at an outside institution prior to the current visit and showed elevation of the left hemidiaphragm with an overlying hypoventilated streak and mild interstitial thickening. Considering the non-specific clinical and radiological findings, a lung ultrasound examination was performed owing to its ready availability and lack of radiation exposure; LUS revealed a small subpleural consolidation in the left subscapular region (suggesting a slowly resolving inflammatory process), normal pleural sliding, non-gravitational B-lines and no pleural e;usion. Perfusion lung scintigraphy excluded pulmonary embolism, but showed di;use hypoperfusion of the left lung; correlated low-dose CT scans revealed a left hilar–parahilar consolidation with bronchial compression and lower lobe atelectasis, along with mediastinal lymphadenopathy. The patient was hospitalized for further investigation and contrast-enhanced whole-body CT and bronchoscopic biopsy confirmed small-cell lung carcinoma.

Conclusions: This case highlights the diagnostic relevance of LUS as an adjunct to physical examination, even in outpatient settings. Although the sonographic findings were non-specific, their integration with the clinical picture prompted additional imaging and enabled an earlier diagnosis of a central lung malignancy that might otherwise have been overlooked. LUS is a valuable, real-time, and radiation-free extension of the pneumological assessment, facilitating timely recognition of clinically significant thoracic disease.

Ultrasound Diaphragmatic Function During Venturi Mask, High Flow Nasal Cannula, and Helmet CPAP in Patients with Acute Hypoxemic Respiratory Failure: A Physiological Comparison

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Rationale: High Flow Nasal Cannula (HFNC) is now a common option for managing acute hypoxemic respiratory failure, yet its physiological impact on the diaphragm is still only partially understood. Clarifying how this device interacts with respiratory mechanics may help refine the choice of non-invasive support in everyday ICU practice**.**

Objectives: The aim of this study was to compare HFNC with Venturi mask and helmet CPAP, focusing on diaphragmatic function, inspiratory effort, and gas exchange. A secondary aim was to examine whether patients with signs of diaphragmatic impairment (identified through a new proposed composite Diaphragmatic Dysfunction Index (DDI)) respond differently to these modalities**.**

Methods: Twenty-eight spontaneously breathing adults with $PaO_2/FiO_2 \leq 300$ mmHg were studied during three consecutive 60-minute periods of respiratory support (Venturi mask, HFNC at 40 L/min, and helmet CPAP set at 3 cmH_2O). Diaphragmatic thickness, thickening fraction, and excursion were assessed through standardized ultrasound measurements, while inspiratory effort was quantified via esophageal pressure swings. Blood gases and respiratory variables were recorded at the end of each phase.

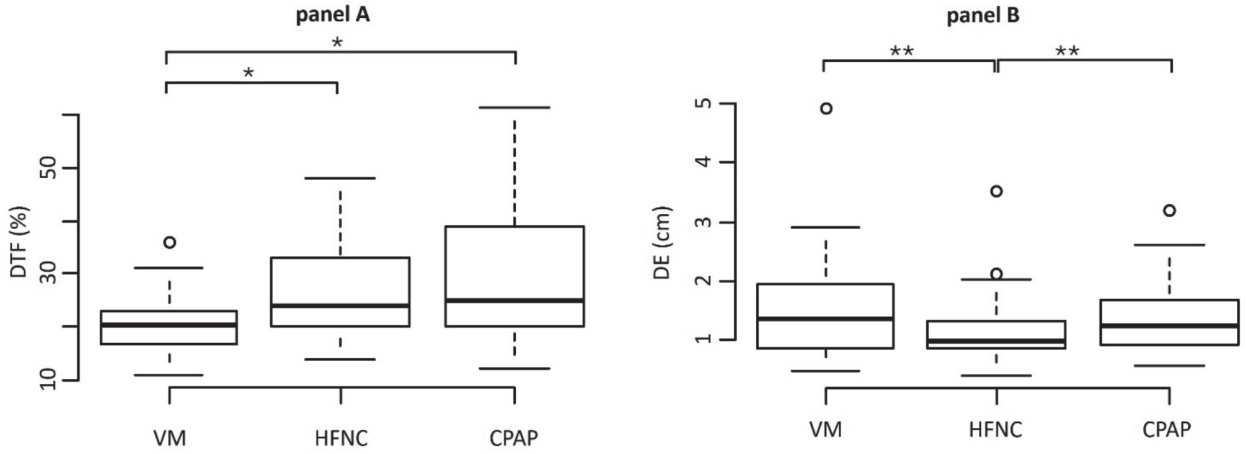
Measurements and Main Results: Compared with the Venturi mask, HFNC produced a clear rise in diaphragmatic thickening fraction and a noticeable reduction in inspiratory effort. Excursion was lower during HFNC, although this appeared consistent with a shift toward a more efficient inspiratory pattern. The full comparison of physiological variables is presented in. When patients were stratified using the DDI, those classified as dysfunctional showed the most marked improvement during HFNC and CPAP, with substantial gains in contractile performance and a pronounced drop in esophageal pressure swings. These differences are summarized in Table 1, while the overall performance of the diaphragm and inspiratory effort across the three modalities is described in Figure 1.

Table 1. Diaphragmatic, esophageal, respiratory gas exchange and hemodynamic variables comparisons of different devices, divided by DDI.

	VM			HFNC			CPAP			ANOVA	
	DDI > 100	DDI < 100	p-value	DDI > 100	DDI < 100	p-value	DDI > 100	DDI < 100	p-value	DDI > 100	DDI < 100
Diaphragmatic ultrasound										p-value	p-value
DTF (%)	17±3.5°#	24±6.4	0.003257	25±8.3*	29±11	ns	26±11*	33±15	ns	0.0070	0.07
DE (cm)	0.98±0.42	2.1±1°#	0.0011	0.81±0.26#	1.4±0.75*	0.01007	1.1±0.34°	1.6±0.67*	0.0154	0.042	<0.0001
Respiratory mechanics											
ΔPes (cmH_20)	9.1±3°#	7±3.8	0.11	5.8±2*	5.9±1.8	ns	6.3±1.9*	5.4±2.3	ns	0.0003	ns
RR (bpm)	26±7.1	24±6	ns	25±6.3	21±6.8	ns	26±6.3	23±7	ns	ns	ns
Gas exchanges											
pH	7.5±0.058	7.4±0.055	0.007539	7.5±0.067	7.4±0.052	0.09	7.5±0.049	7.4±0.04	0.0091	ns	ns
pCO_2 (mmHg)	37±8.1	41±12	ns	38±9.4	39±12	ns	38±7.2	40±9.7	ns	ns	ns
pO_2 (mmHg)	62±14	65±14#	ns	71±7.2	69±15#	ns	75±21	78±13°°	ns	0.0389	<0.0001

*statistically different from VM in *post hoc* ANOVA; #statistically different from CPAP in *post hoc* ANOVA; °statistically different from HFNC in *post hoc* ANOVA.

Figure 1. Overall performance of the diaphragm and inspiratory effort across the three modalities: diaphragmatic, esophageal, respiratory gas exchange variables.



Conclusions: HFNC supports diaphragmatic function and reduces the mechanical load of breathing more effectively than the Venturi mask, with the strongest effect observed in patients showing signs of diaphragmatic dysfunction. These findings reinforce the value of a physiology-based, individualized approach when selecting noninvasive respiratory support.