J Ultrasound (2015) 18:379–384
DOI 10.1007/s40477-014-0122-5

PICTORIAL ESSAY

# Ultrasound in obstructive lung diseases: the effect of airway obstruction on diaphragm kinetics. A short pictorial essay

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Received: 5 May 2014 / Accepted: 16 July 2014 / Published online: 1 August 2014


**Abstract** The ultrasound study of the chest is showing a continuous development. This technique could be helpful in managing several chest diseases, but it is limited to the acoustic windows provided by intercostal spaces and by the inability to study healthy lung parenchyma and all intraparenchymal diseases such as chronic obstructive lung disease (COPD), because the interaction between ventilated lung and ultrasound generates only artifacts. Currently, there are few applications of ultrasound that are useful in COPD, with recent studies providing some innovation potentially useful in clinical practice. The similarity of the trend between the time/volume curve of spirometry and the M-mode representation of diaphragm during forced breath allowed to identify the M-mode Index of Obstruction (MIO), an index obtained from the ratio between forced diaphragmatic excursion in the first second (FEDE1, cm) and the maximal expiratory diaphragmatic excursion (EDEMax, cm). MIO has shown a linear correlation with the ratio between forced expiratory volume in the first second (FEV1) and vital capacity (VC), used in spirometry to identify airways obstruction. The value of MIO seems to be lower in patients affected by airways obstruction as showed by a recent study. The technique is easy to learn and fast to perform and the analysis could be provided with any ultrasound machine equipped with M-mode. In conclusion, these findings, if confirmed by other studies, could suggest a new add-on screening tool for obstructive lung diseases, in particular COPD, that could be performed during a routine abdominal ultrasound exam.

**Keywords** Ultrasound · Diaphragm · Chronic obstructive pulmonary disease · Airway obstruction

**Riassunto** Lo studio ecografico del torace sta conoscendo un crescente sviluppo. Questa tecnica può essere di aiuto nella gestione di svariate patologie del torace, ma è limitata alle finestre acustiche fornite dagli spazi intercostali e dall'incapacità di studiare il parenchima polmonare sano e tutte le patologie intraparenchimali come la Broncopneumopatia Cronica Ostruttiva (BPCO), poiché l'interazione tra il polmone ventilato e gli ultrasuoni genera solo artefatti. Attualmente, ci sono poche applicazioni dell'ecografia fruibili nella BPCO, e alcuni studi recenti forniscono degli spunti innovativi potenzialmente utili nella pratica clinica. La somiglianza dell'andamento della curva spirometrica volume/tempo e della rappresentazione ecografica in M-mode della cinetica diaframmatica durante una manovra di espiro forzato ha consentito di identificare l'Indice di ostruzione in M-mode (MIO), un indice ottenuto dal rapporto tra l'escursione diaframmatica forzata nel primo secondo (FEDE1, cm) e l'escursione diaframmatica espiratoria massimale (EDEMax, cm), mostra una correlazione con il rapporto tra il volume espiratorio forzato nel primo secondo (FEV1) e la capacità vitale (VC), utilizzato nella spirometria per identificare l'ostruzione delle vie aeree. Il valore di MIO sembra essere inferiore nei pazienti affetti da ostruzione della vie aeree come evidenziato da uno studio recente. La tecnica è facilmente apprendibile ed eseguibile e l'analisi può essere ottenuta con qualunque ecografo dotato di M-mode. In conclusione, questi

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riscontri, se confermati da altri studi, potrebbero suggerire una nuova ulteriore tecnica di screening per le patologie ostruttive, in particolare la BPCO, che potrebbe essere eseguita durante una ecografia addominale di routine.

## Introduction

Some years ago, chest ultrasound had a marginal role in respiratory medicine because the technique is conditioned by the physical properties of ventilated lung that is shown by ultrasound as a combination of artifacts. However, thanks to recent studies that have underlined its usefulness in diagnosis and follow-up of respiratory diseases such as pneumothorax, acute and chronic interstitial diseases, pneumonia and pleural effusion, chest ultrasound has been developed in the last decade, with an increasing interest in respiratory units, internal medicine and in critical care [1–4]. The transthoracic ultrasound analysis of pulmonary circle and airways is not possible in a well-ventilated lung. Disease of pulmonary circle can be detected by heart ultrasound, but actually there are few ultrasound applications available that could be useful in airways diseases such as asthma and chronic obstructive lung disease (COPD).

Some authors [5, 6] have proposed ultrasound assessment of lower limb muscles to quantify the improvements following resistance training. Scanning was performed at the mid-thigh region, and quadriceps mass was assessed by measuring rectus femoris cross-sectional area (RFcsa) and quadriceps muscle thickness (Qt). The study observed that the changes assessed by ultrasound were greater than the changes in dual-energy X-ray absorptiometry (DEXA), in patients with COPD and healthy controls following a program of resistance training.

It has been observed that sometimes COPD could mimic a pneumothorax because of the lack of sliding of pleural line [7], maybe due to poor pulmonary excursion secondary to severe pulmonary function.

The more known application of ultrasound related to COPD is probably the use of point of care ultrasound in the evaluation of acute dyspnea: it has been described as the finding of a B-lines pattern (interstitial syndrome) suggests a pulmonary edema and rules out COPD, so the exacerbation of chronic bronchitis remains an exclusion diagnosis [8]. In spite of this point of view, a multicenter study performed on 193 patients with acute dyspnea versus 193 healthy subjects and 58 pneumonectomized patients has shown that the count of B-lines seems to increase in all patients with acute dyspnea, but the count seems not to be useful in differential diagnosis of dyspnea [9].

Recently, Smargiassi et al. [10] have shown the possible role of echographic measurement of diaphragm thicknesses in transthoracic approach at the zone of apposition (the area in which diaphragm adheres to thoracic wall) in COPD patients. It has been demonstrated that the measurement of both thickness and thickening of the diaphragm at the end of a maximal inspiration might be a useful tool to estimate lung hyperinflation when adjusted for fat-free mass (FFM). It has been found a progressive reduction of both thicknesses and thickenings as the severity of the ratio inspiratory capacity/total lung capacity (IC/TLC) increases, with a significant $p$ value for the trend in both analyses. Thus, this technique could be helpful for studying disease progression in COPD patients, in terms of lung hyperinflation and the loss of FFM. In the same work no correlations have been found between respiratory functional parameters and the measurement of the right hemidiaphragmatic excursion itself.

The possible role of ultrasound in the functional evaluation of COPD patients has been suggested by Dos Santos Yamaguti et al. [11] showing that diaphragm mobility, measured as a craniocaudal displacement, has a strong correlation with airtrapping.

A better analysis of diaphragm kinetics is provided by a transhepatic scan using M-mode, by directing the ultrasound beam perpendicular to diaphragmatic dome. In M-mode representation diaphragm appears as a thick hyperechoic line approaching to the probe in inspiration and moving away from the probe in expiration. This visualization of diaphragm, although with different approaches, has been described by some authors [12–19]. The right hemidiaphragm can be studied in most cases by this approach; meanwhile the left dome could be often masked by artifacts generated by air in bowel and stomach [12]. These studies performed a “static” measure of diaphragm motion obtained with the distance between end-inspiratory and end-expiratory position of diaphragm during spontaneous and forced breath and analyzed diaphragm motion in different approaches, generating some differences in mean values due to a parallax error [19].

A recently published study (ECOSPIR) has shown for the first time a relationship between diaphragm kinetics analyzed with ultrasound and lung function using the M-mode Index of Obstruction (MIO) [20]. The MIO is a ratio between the measure of diaphragm expiratory excursion expressed in centimeters in the first second during a forced open-mouth breath (FEDE1) and the total expiratory excursion (EDEMax) expressed in centimeters. These measures are taken analysing with M-mode the movements of diaphragm during an expiratory maximal effort through a transhepatic transverse oblique scan. MIO has shown a linear correlation with the ratio between forced expiratory volume in the first second (FEV1) and vital capacity (VC), used in spirometry to identify airways obstruction. What is innovative, is the correlation between MIO values and lung function, in particular the study

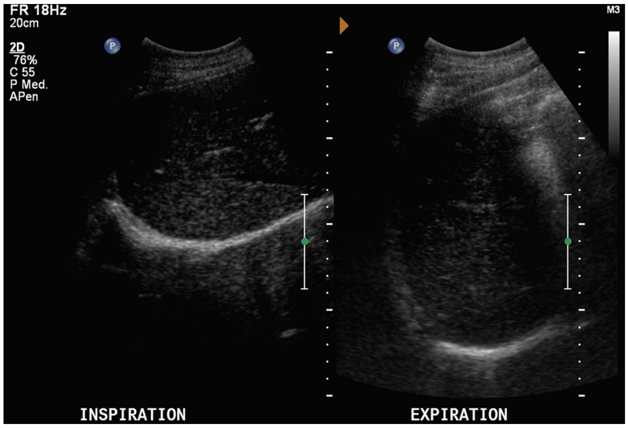


**Fig. 1** Transverse subcostal ascendent scan of right diaphragmatic dome showing the hyperechoic diaphragmatic line surrounding the liver. In the *left picture*, taken during inspiration, diaphragm is lowered by contraction, so it approaches the probe and it is represented higher. In the *right picture*, taken in respiration, the diaphragm is more far from the probe because during relaxation the muscle rises and it is represented lower (iE33 with convex probe c5-1, Koninklijke Philips N.V., Eindhoven, The Netherlands)

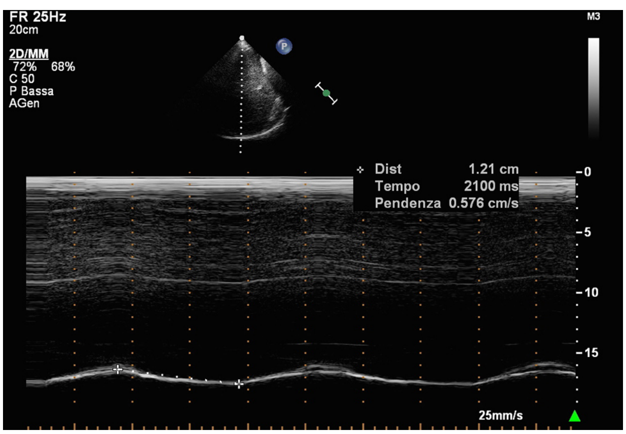


**Fig. 2** M-mode representation of diaphragm kinetics during spontaneous breathe. The diaphragm is represented as a hyperechoic line ascending in inspiration and descending in expiration. The taken measure shows a diaphragmatic excursion of 1.21 cm during spontaneous breathe (iE33 with sector probe s5-1, Koninklijke Philips N.V., Eindhoven, The Netherlands)

indicates as lower MIO values seem to be generally associated with an obstructive spirometric pattern [20]. The diagnosis of obstruction on spirometry was stated following international guidelines on interpretation of lung function tests [21].

## Ultrasound patterns of diaphragm kinetics in normal and obstructed patients

With patient in semi-recumbent position, we perform a transverse oblique ascending scan of the right hepatic lobe with a convex probe using an abdominal standard preset. Focus has to be set on diaphragm line. Diaphragm will appear as a white curve line surrounding liver and representing the interface between liver and ventilated lung.

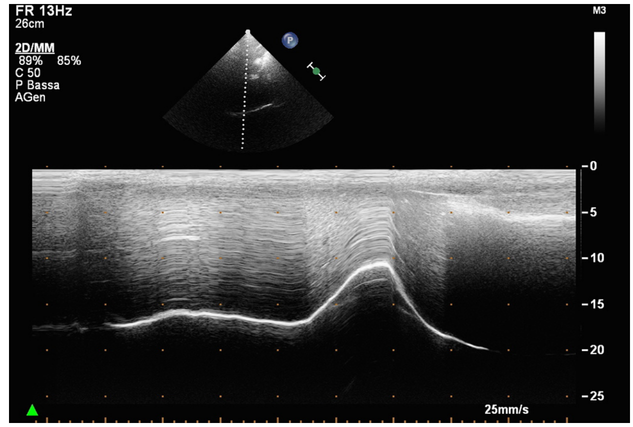


**Fig. 3** M-mode representation of diaphragm kinetics during forced breathe. The patient is asked to take a deep breathe and the diaphragmatic line rises higher than during spontaneous breathe, reaching a plateau. Then the patient is asked to have a forced and maximal open-mouth expiration and the line shows an initial drop off followed by an end-expiratory plateau (iE33 with sector probe s5-1, Koninklijke Philips N.V., Eindhoven, The Netherlands)

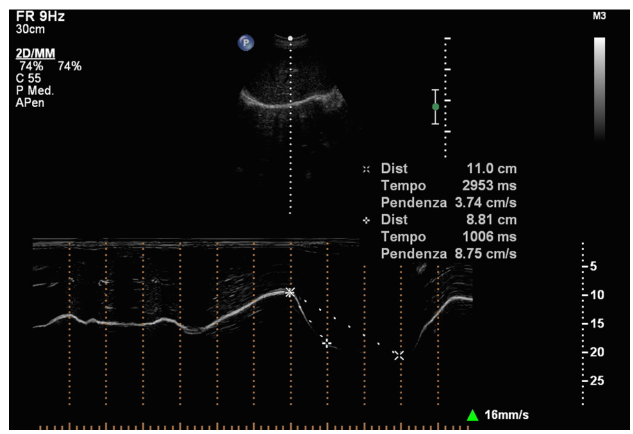


**Fig. 4** M-mode representation of diaphragm kinetics during forced breathe in a normal subject. The measure of FEDE1 (+, 8.81 cm) is taken from the beginning of expiration up to 1 s on the diaphragmatic line. The measure of EDEMax (x, 11 cm) is taken from the beginning of expiration up to the end of expiratory plateau. The ratio FEDE1/EDEMax (MIO) is 80.09, suggesting a normal pattern (iE33 with convex probe c5-1, Koninklijke Philips N.V., Eindhoven, The Netherlands)

With patient breathing we can observe the diaphragm approaching the probe in inspiration and moving away from the probe in expiration (Fig. 1).

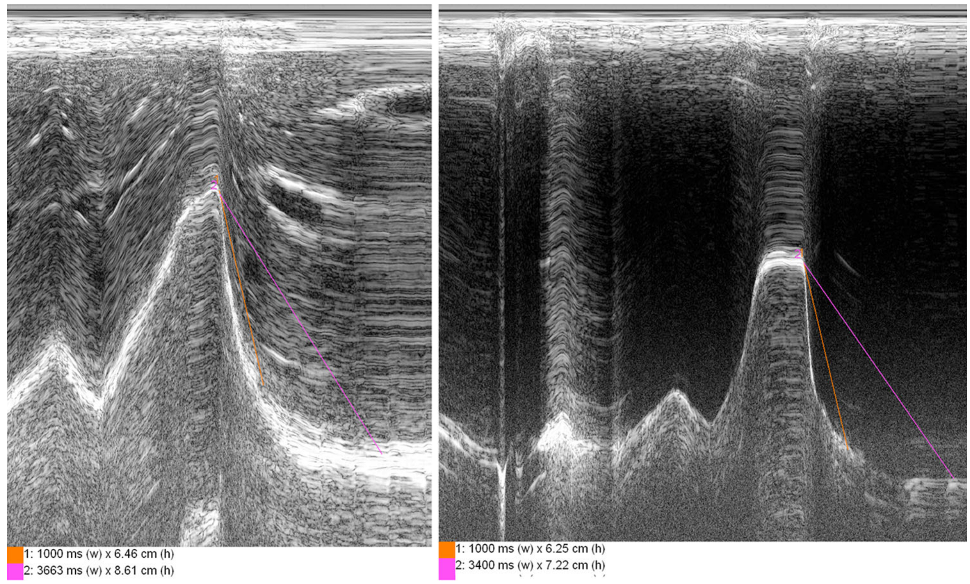


**Fig. 5** M-mode representation of diaphragm kinetics during forced breathe performed with a handheld portable ultrasound. *Left image* obstructed patient (FEDE1 = 6.46 cm; EDEMax = 8.61 cm; MIO = 75.03). *Right image* normal subject (FEDE1 = 6.25 cm; EDEMax = 7.22 cm; MIO = 86.56). (Signos with 3.5 MHz anular array probe, Signostics Ltd, Thebarton, SA, Australia)

Activating M-mode vision and selecting a line passing through the hepatic dome, diaphragm is represented as a hyperechoic line ascending during inspiration and descending in expiration (Fig. 2). With patient breathing quietly we can measure the diaphragmatic excursion related to current volume respiration.

When patient takes a deep breath the diaphragmatic line goes up until it reaches a plateau in maximal inspiration. Then we ask patient to perform a maximal open-mouth expiration: the diaphragmatic line has an initial drop-off followed by a plateau at the end of expiration (Fig. 3).

In this image, we can obtain FEDE1 measuring the distance (cm) between the point in which expiration starts and a point on the diaphragmatic line after 1 s. EDEMax can be obtained measuring the distance (cm) between the start-expiration point and the point on end-expiratory plateau before the next inspiration. MIO will be the ratio (FEDE1/EDEMax) between the two values (Fig. 4).

The maneuver is easy to perform and could be provided, although with different image resolution, with any ultrasound machine equipped with low-frequency probe (convex, sector) and M-mode (Fig. 5).

In obstructed patients, affected by asthma or chronic obstructive pulmonary disease (COPD), the values of MIO are lower than in normal subjects, because the airtrapping generated by increased airway resistance reduces the output of air from the chest generating higher intrinsic pressure that cause a slower relaxation of the diaphragm in expiration. The delay of diaphragmatic relaxation is represented as a reduced inclination of expiratory drop-off with consequent lower values of FEDE1 and MIO. (Fig. 6) Using a ratio between two values taken from the same scan the parallax error potentially generated by probe orientation has been avoided.

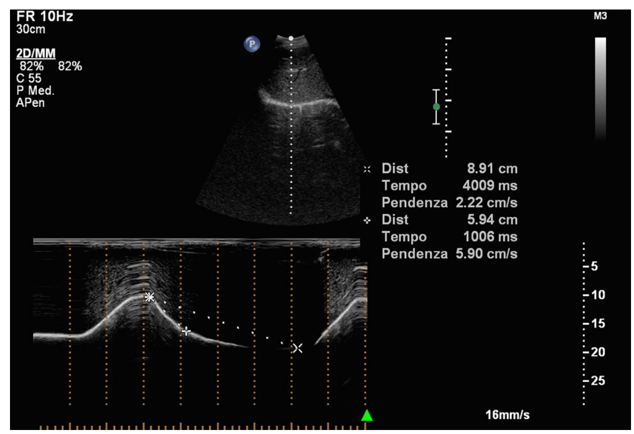


**Fig. 6** M-mode representation of diaphragm kinetics during forced breathe in an obstructed patient. FEDE1 = 5.94 cm; EDEMax = 8.91 cm. The ratio FEDE1/EDEMax (MIO) is 66.66, suggesting an obstructive pattern. (iE33 with convex probe c5-1, Koninklijke Philips N.V., Eindhoven, The Netherlands)

## Conclusions

The preliminary results of this technique show that calculating MIO we could suspect the presence of airways obstruction [20]. Some patients included in the study were affected by asthma, others by COPD. Following its definition, asthma is characterized by variable obstruction, but often the patient can present a normal spirometric pattern

[22], meanwhile COPD is defined as a lung disease with chronic obstruction. This means that a COPD patient always presents an obstructive spirometric pattern [23]. Analyzing the subset of COPD patients in the ECOSPIR study, we have the confirmation that these patients have lower values of MIO versus normal subjects. However, COPD is often underdiagnosed [24] but associated with better diagnosed comorbidities (i.e., systemic arterial hypertension, diabetes) [23] requiring often an evaluation of abdominal organs. Abdominal ultrasound is a widespread exam performed with various indications (including a general health condition evaluation) in radiology and internal medicine units. The exam takes from 15 to 30 min and includes always the study of liver, so a visualization of right hemidiaphragm could always be performed. The additional evaluation of diaphragm excursion during a forced expiration would take few more minutes without significatively prolonging the exam and consequently without additional costs.

In this sense, the aim of future studies will be to assess if this technique could provide a new screening tool for detecting COPD during a routine abdominal ultrasound exam.

**Conflict of interest** Alessandro Zanforlin, Andrea Smargiassi, Riccardo Inchingolo, Salvatore Valente, and Emilio Ramazzina declare that they have no conflict of interest.

**Informed consent** All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000. All patients provided written informed consent to enrolment in the study and to the inclusion in this article of information that could potentially lead to their identification.

**Human and animal studies** The study was conducted in accordance with all institutional and national guidelines for the care and use of laboratory animals.

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