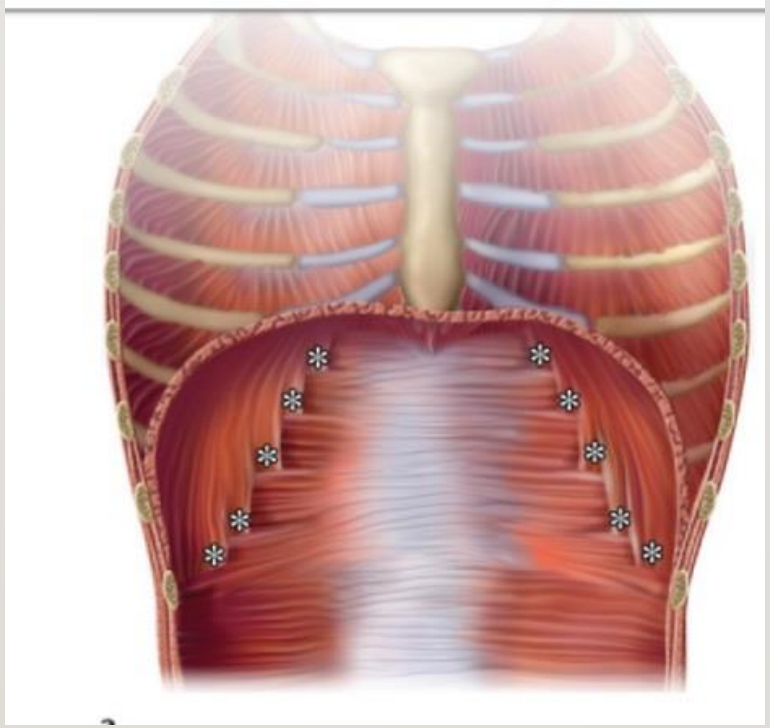
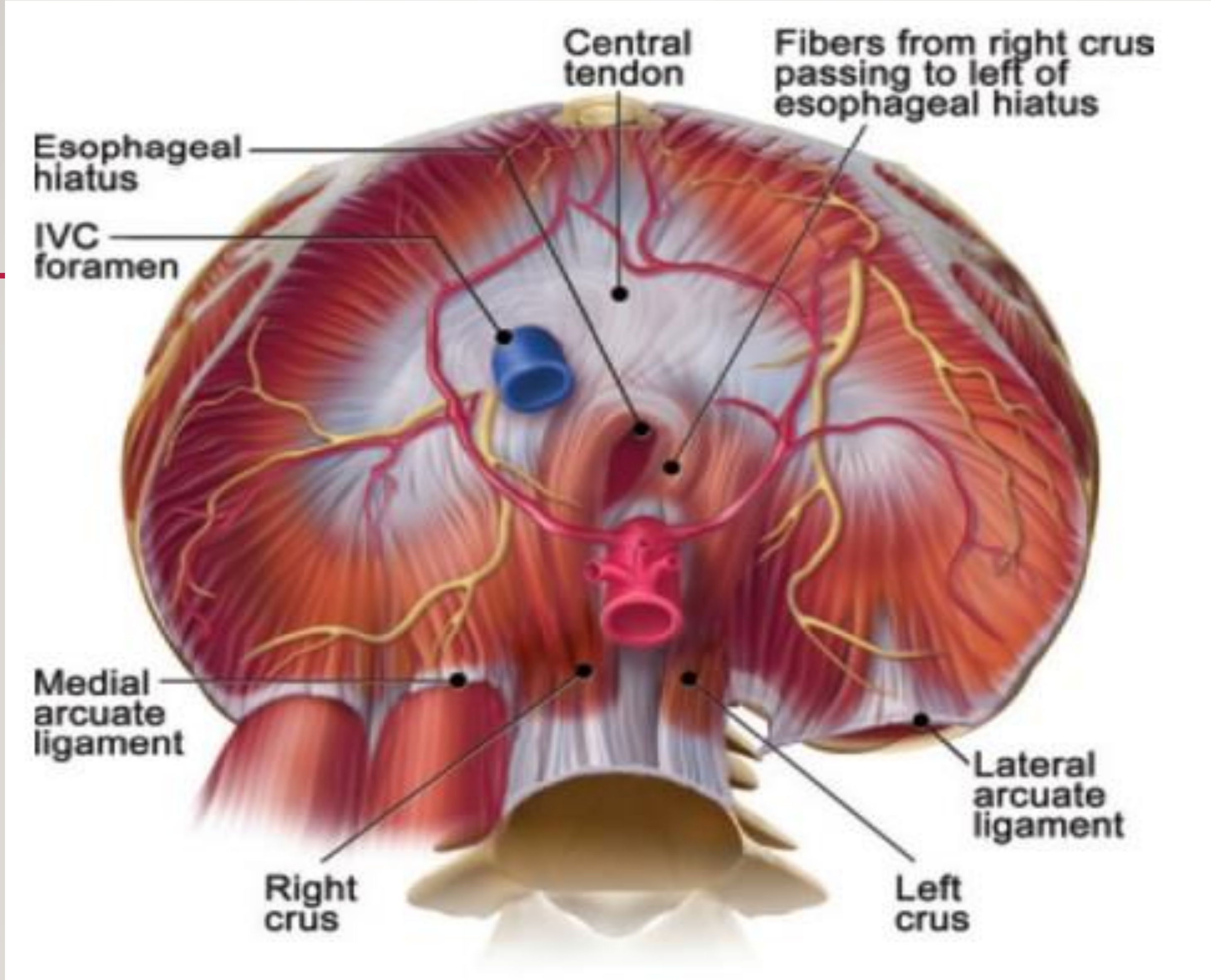
ΤΟ ΔΙΑΦΡΑΓΜΑ
ΥΠΕΡΗΧΟΓΡΑΦΙΚΟΣ ΕΛΕΓΧΟΣ

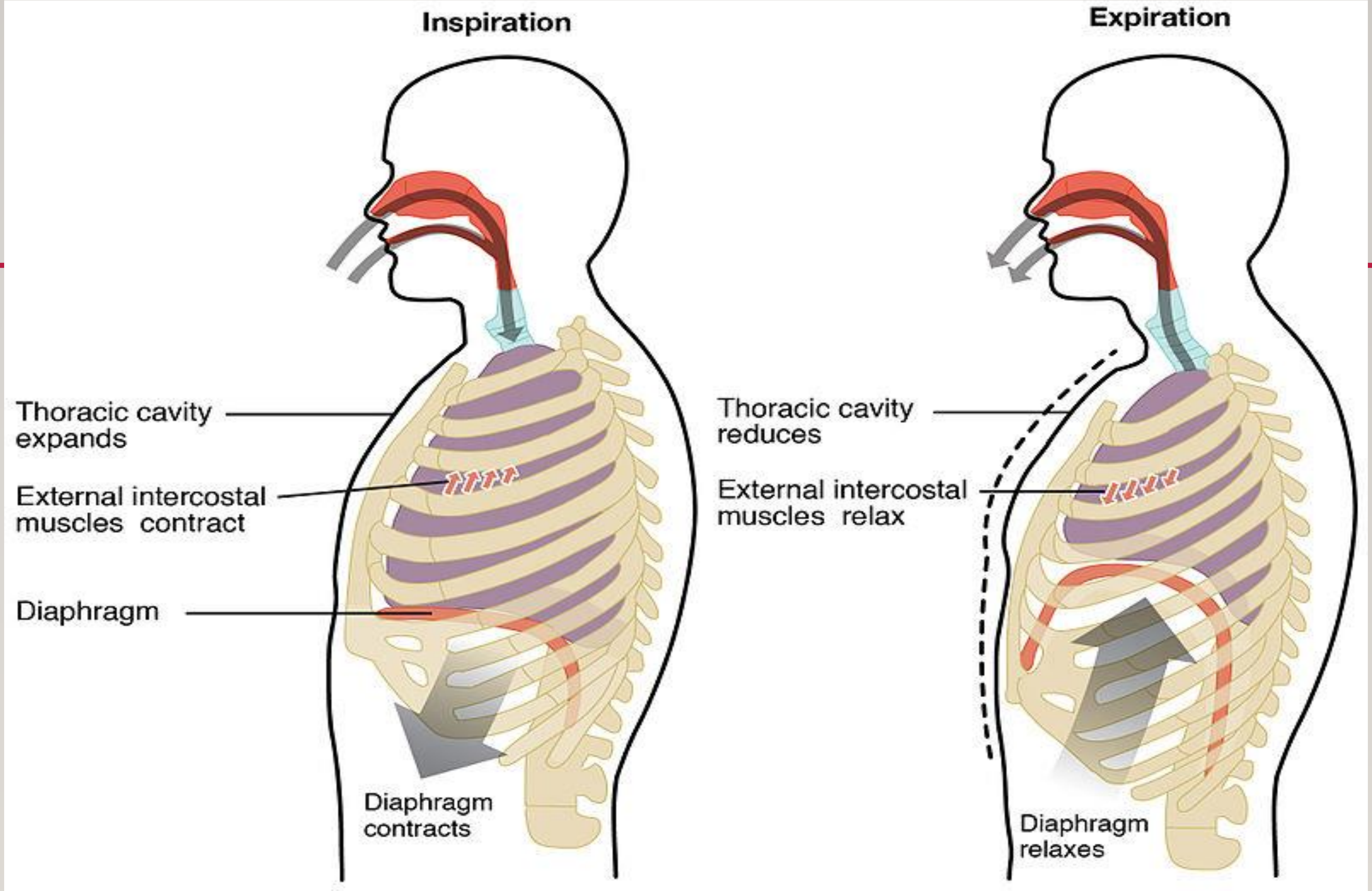
ΒΟΥΤΣΑΣ ΒΑΣΙΛΕΙΟΣ

ΠΝΕΥΜΟΝΟΛΟΓΟΣ –ΕΝΤΑΤΙΚΟΛΟΓΟΣ

ΕΠΙΜΕΛΗΤΗΣ ΕΣΥ Α’ΜΕΘ Γ.Ν.Θ. ‘Γ.ΠΑΠΑΝΙΚΟΛΑΟΥ’




Central tendon
Fibers from right crus passing to left of esophageal hiatus
Esophageal hiatus
IVC foramen
Medial arcuate ligament
Lateral arcuate ligament
Right crus
Left crus


Inspiration
Expiration
Thoracic cavity
expands
External intercostal
muscles contract
Diaphragm
Diaphragm
contracts
Thoracic cavity
reduces
External intercostal
muscles relax
Diaphragm
relaxes

ΔΙΑΦΡΑΓΜΑ

- Έλεγχος της κίνησης κατά τις αναπνευστικές κινήσεις (EXCURSION)
- Έλεγχος του πάχους του διαφράγματος (THICKNESS)
- Έλεγχος της πάχυνσης του διαφράγματος κατά τις αναπνευστικές κινήσεις (THICKENING FRACTION)

EXCURSION

- The two-dimensional (2D) mode is initially used to obtain the best approach and select the exploration line;
- the M-mode is then used to display the motion of the anatomical structures along the selected line

αμέσως κάτω από το πλευρικό τόξο , στην μεσοκλειδική ή την πρόσθια μασχαλιαία γραμμή, κάθετα με κατεύθυνση ραχιαία και πάνω, με ακουστικό παράθυρο το ήπαρ ή το σπλήνα

- Diaphragmatic sonography is performed using a 3.5–5 MHz phased array probe.
- The probe is placed immediately below the right or left costal margin in the mid-clavicular line, or in the right or left anterior axillary line and is directed medially, cephalad and dorsally,
- so that the ultrasound beam reaches perpendicularly the posterior third of the corresponding hemi-diaphragm

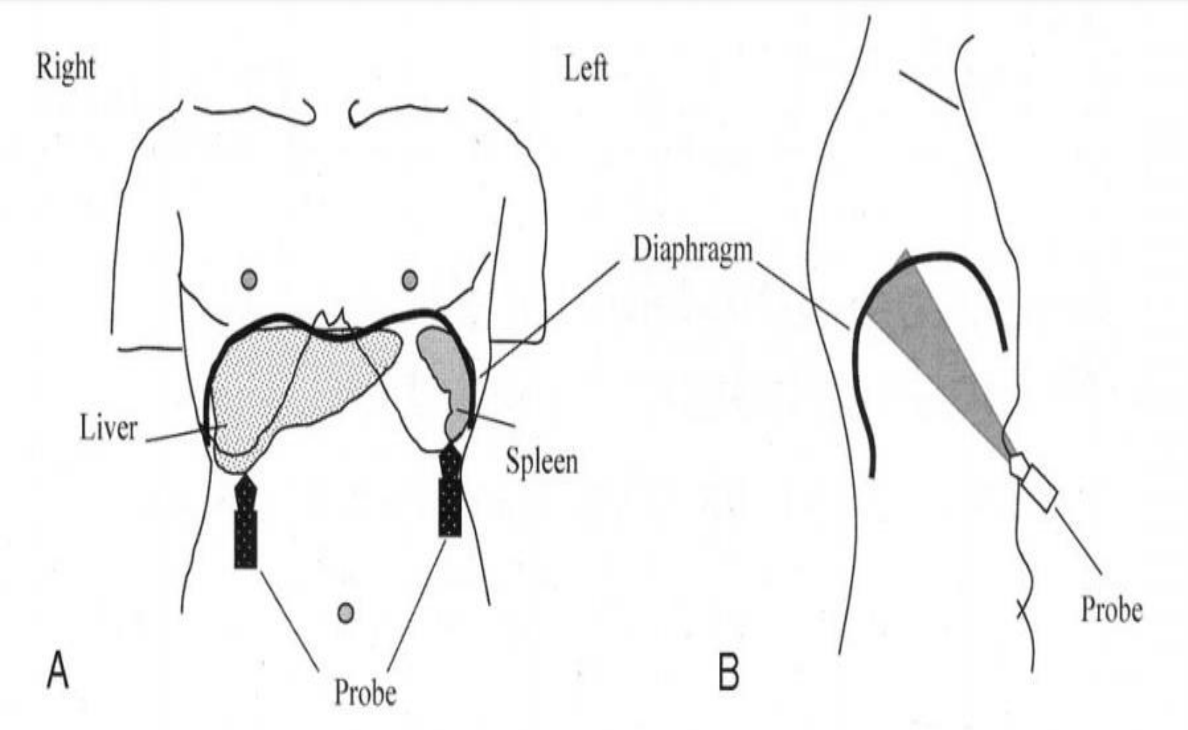


FIGURE 1. Ultrasonographic approach of the right and left hemidiaphragms. The liver and spleen were used as acoustic windows. *Left*, *A*: For the right hemidiaphragmatic study, the probe was positioned below the right costal margin between the midclavicular and anterior axillary lines. The left diaphragmatic was studied from a low intercostal or subcostal approach. The probe was positioned between the midaxillary and anterior axillary lines. *Right*, *B*: The probe angled cranially so that the ultrasound beam reached perpendicularly the posterior part of the diaphragm.

CHEST Original Research
ULTRASONOGRAPHY

Diaphragmatic Motion Studied by M-Mode Ultrasonography*

Methods, Reproducibility, and Normal Values

Alain Boussuges, MD, PhD; Yoann Gole, MSc; and Philippe Blanc, MD

Background: Although diaphragmatic motion is readily studied by ultrasonography, the procedure remains poorly codified. The aim of this prospective study was to determine the reference values for diaphragmatic motion as recorded by M-mode ultrasonography.
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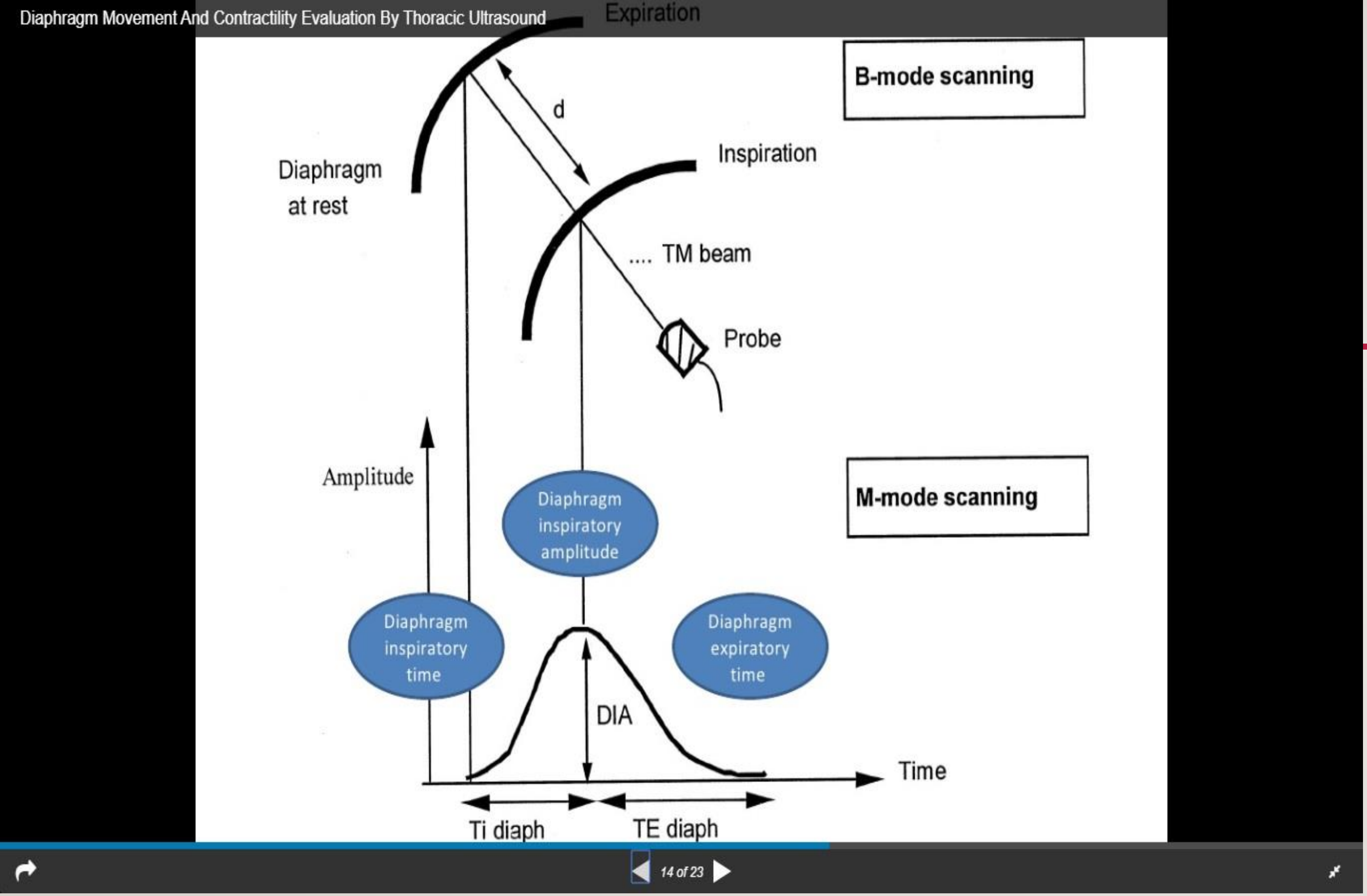
Results: Right and left diaphragmatic motions were successfully assessed during quiet breathing in all subjects. During voluntary sniffing, the measurement was always possible on the right side, and in 208 of 210 volunteers, on the left side. During deep breathing, an obscuration of the diaphragm by the descending lung was noted in subjects with marked diaphragmatic excursion. Consequently, right diaphragmatic excursion could be measured in 195 of 210 subjects, and left diaphragmatic excursion in only 45 subjects. Finally, normal values of both diaphragmatic excursions were determined. Since the excursions were larger in men than in women, the gender should be taken into account. The lower limit values were close to 0.9 cm for women and 1 cm for men during quiet breathing, 1.6 cm for women and 1.8 cm for men during voluntary sniffing, and 3.7 cm for women and 4.7 cm for men during deep breathing.
Conclusions: We demonstrated that M-mode ultrasonography is a reproducible method for assessing hemidiaphragmatic movement. *(CHEST 2009; 135:391–400)*


Diaphragm Movement And Contractility Evaluation By Thoracic Ultrasound
Expiration
B-mode scanning
d
Diaphragm
at rest
Inspiration
.... TM beam
Probe
Amplitude
Diaphragm
inspiratory
amplitude
M-mode scanning
Diaphragm
inspiratory
time
Diaphragm
expiratory
time
DIA
Time
Ti diaph
TE diaph
14 of 23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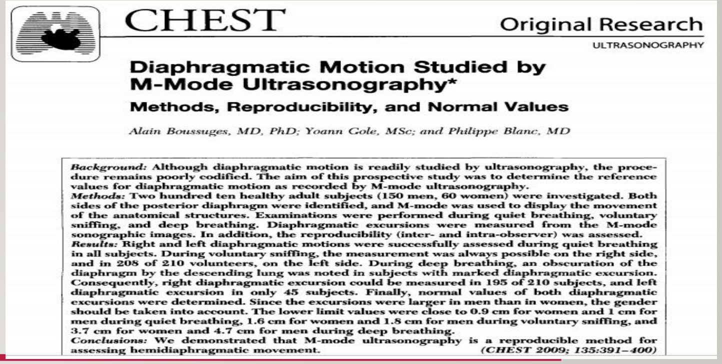
Care Physician who is interested in ultrasound
Bassel Ericsoussi, MD
Diaphragm Movement and
Contractility Evaluation by Thoracic
Ultrasound:
Ultrasonography Determination of Diaphragmatic Excursion
Bassel Ericsoussi, MD
Pulmonary and Critical Care Fellow
University of Illinois at Chicago

www.chestjournal.org/content/135/2/391/F3.large.jpg



CHEST Original Research
ULTRASONOGRAPHY

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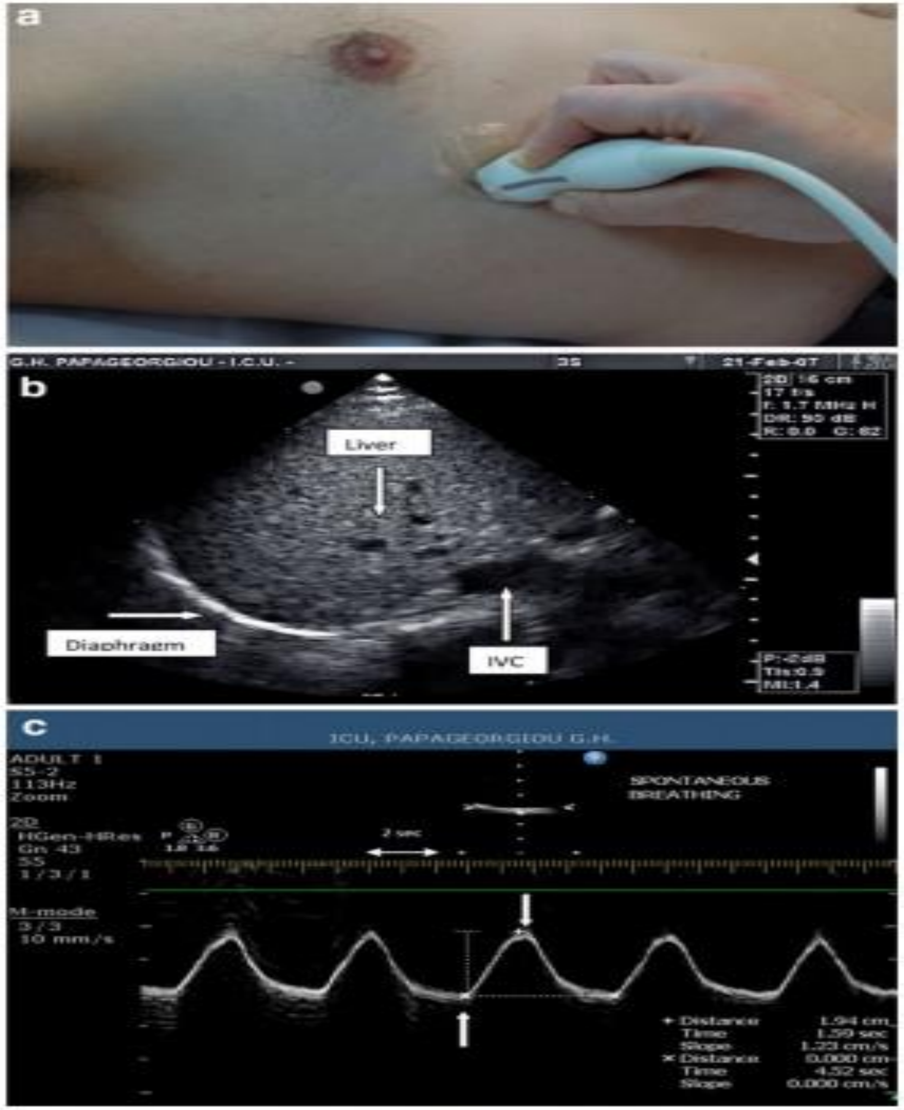

Intensive Care Med (2013) 39:801–810
DOI 10.1007/s00134-013-2823-1

REVIEW

Dimitrios Matamis
Eleni Soilemezi
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Saoussen Dimassi
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Jean-Christophe M. Richard
Laurent Brochard

Sonographic evaluation of the diaphragm in critically ill patients. Technique and clinical applications

- Patients are scanned along the long axis of the intercostal spaces, with the liver serving as an acoustic window to the right, and the spleen to the left.
- Normal inspiratory diaphragmatic movement is caudal, since the diaphragm moves toward the probe; normal expiratory trace is cranial, as the diaphragm moves away from the probe

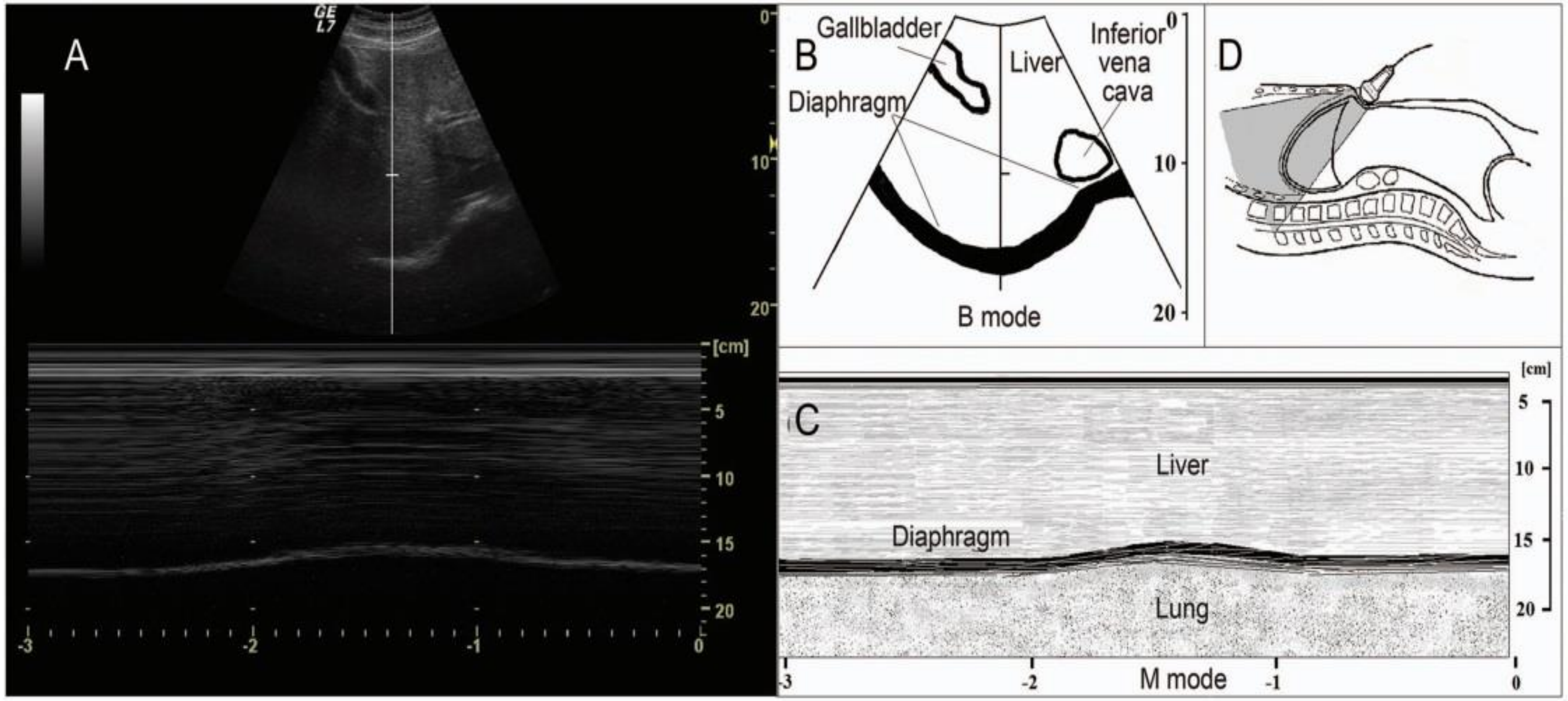


Fig. 4. Ultrasonographic assessment of diaphragm displacement. A: Ultrasonographic view of the normal diaphragm in the region of the live dome, with B-mode in the upper part and M-mode in the lower part. B: Anatomical structures that can be identified in B-mode scanning C: Anatomical structures that can be identified in M-mode scanning. D: Probe placement to explore the diaphragm in the region of the live dome.

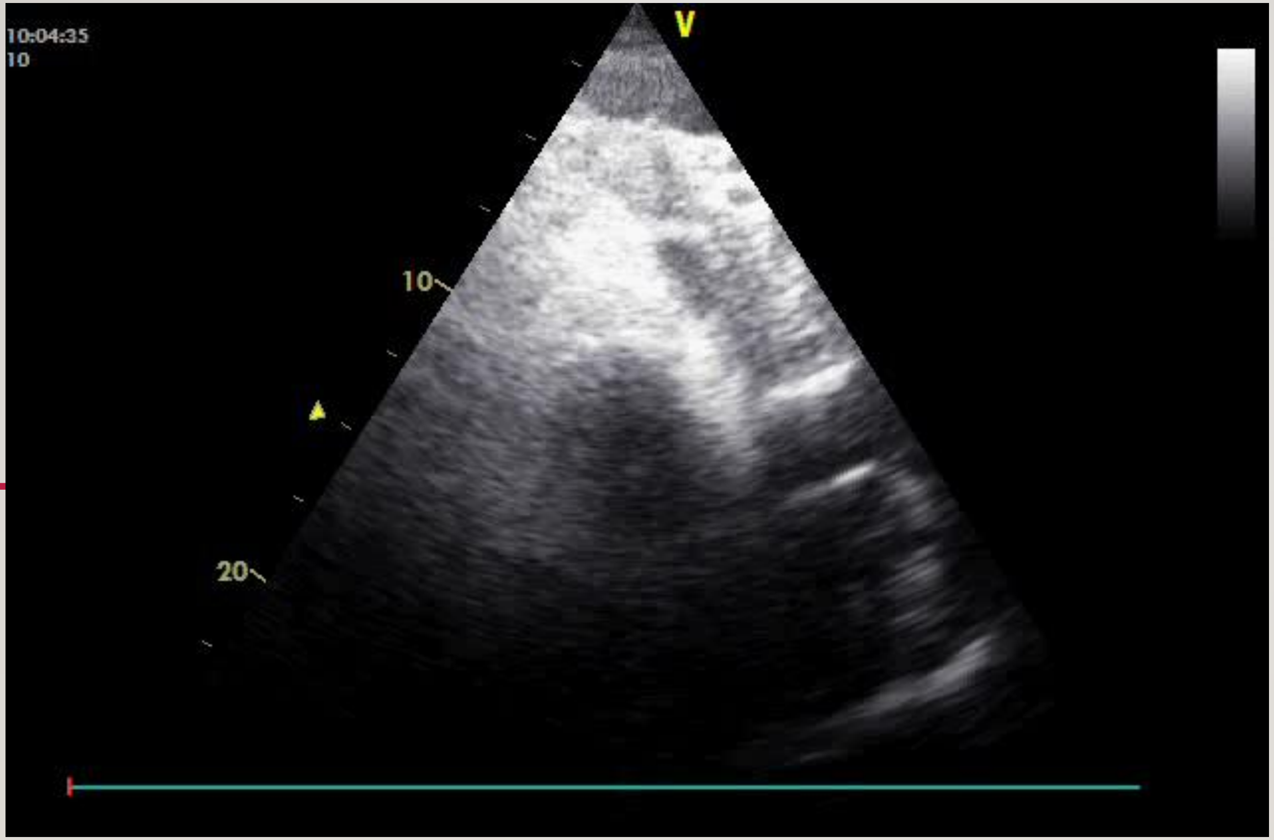
Ultrasonographic Assessment of Diaphragm Function in Critically Ill Subjects

Michele Umbrello MD and Paolo Formenti MD

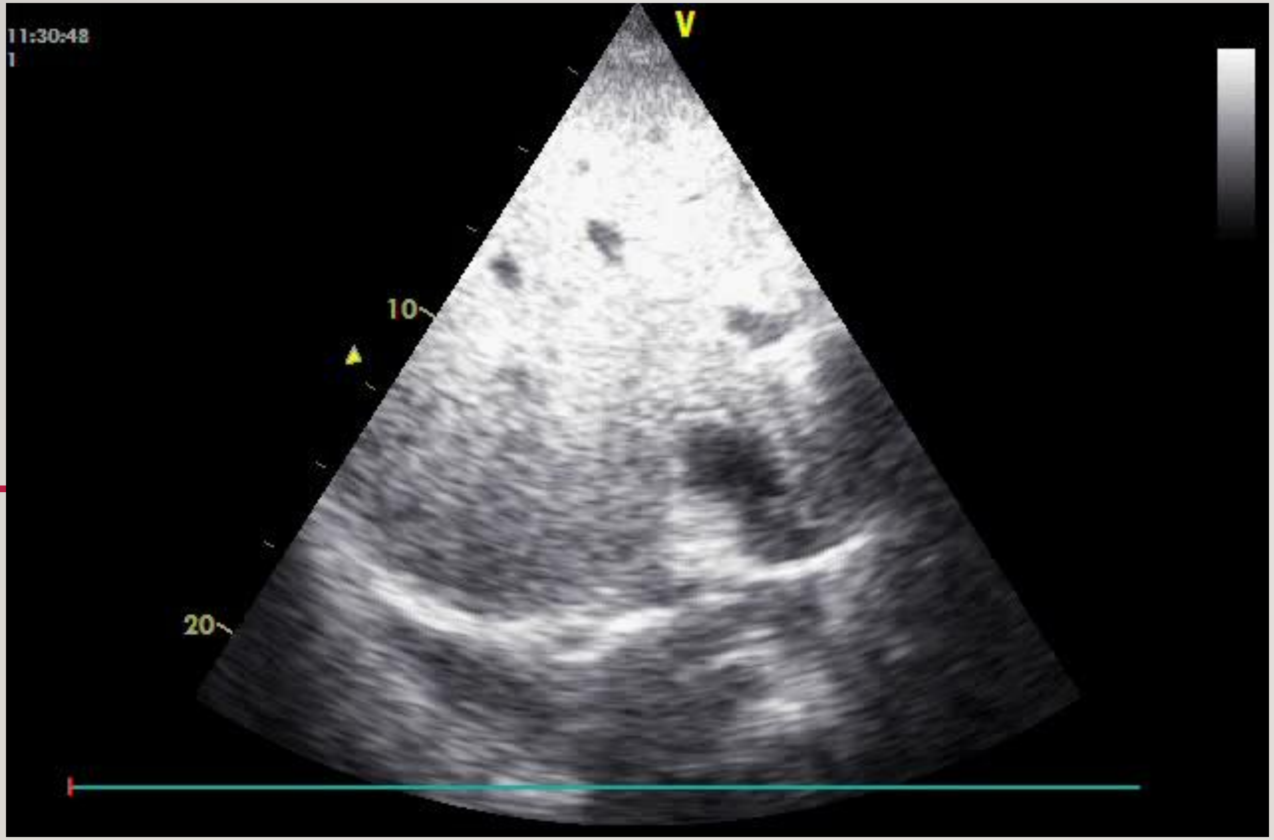
RESPIRATORY CARE • APRIL 2016 VOL 61 NO 4

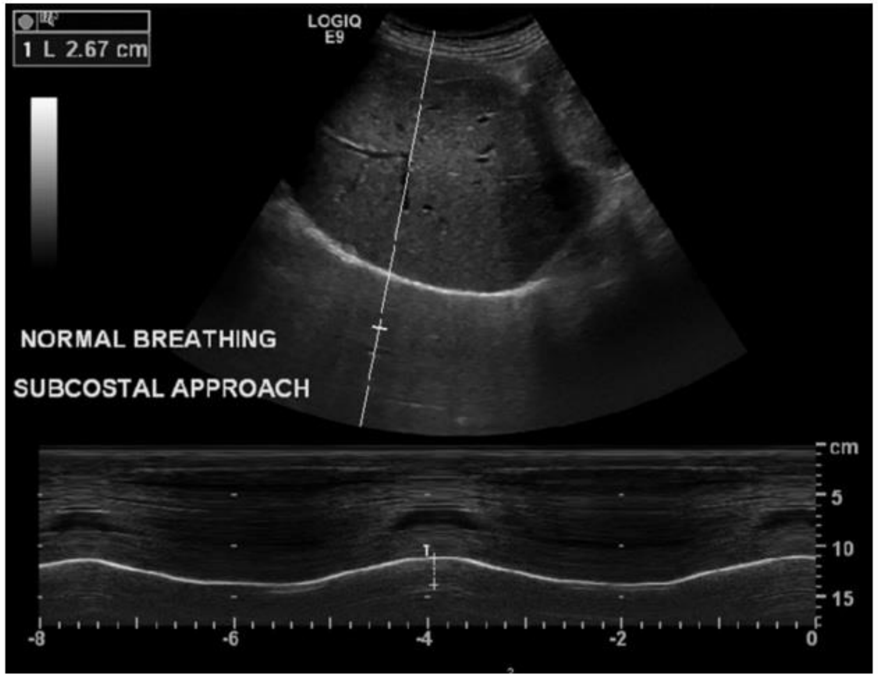

18:35:08
1
V
10
20


18:36:17
4
V
10
20


10:04:35
10
V
10
20

11:32:31
4
V
10
20


11:30:48
1
V
10
20



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Ultrasound in the evaluation of diaphragm

Poster No.:	C-2402
Congress:	ECR 2015
Type:	Educational Exhibit
Authors:	D. Roriz[1], I. Abreu[2], P. Belo Soares[3], F. Caseiro Alves[4]; [1]PT, [2]Porto/PT, [3]Mem Martins/PT, [4]Coimbra/PT

SNIFF

- a maximal sniff:
- The latter is defined as a short, sharp inspiratory effort through the nose and it is thought to be a reproducible and quantitative assessment of diaphragmatic strength

SNIFF TEST

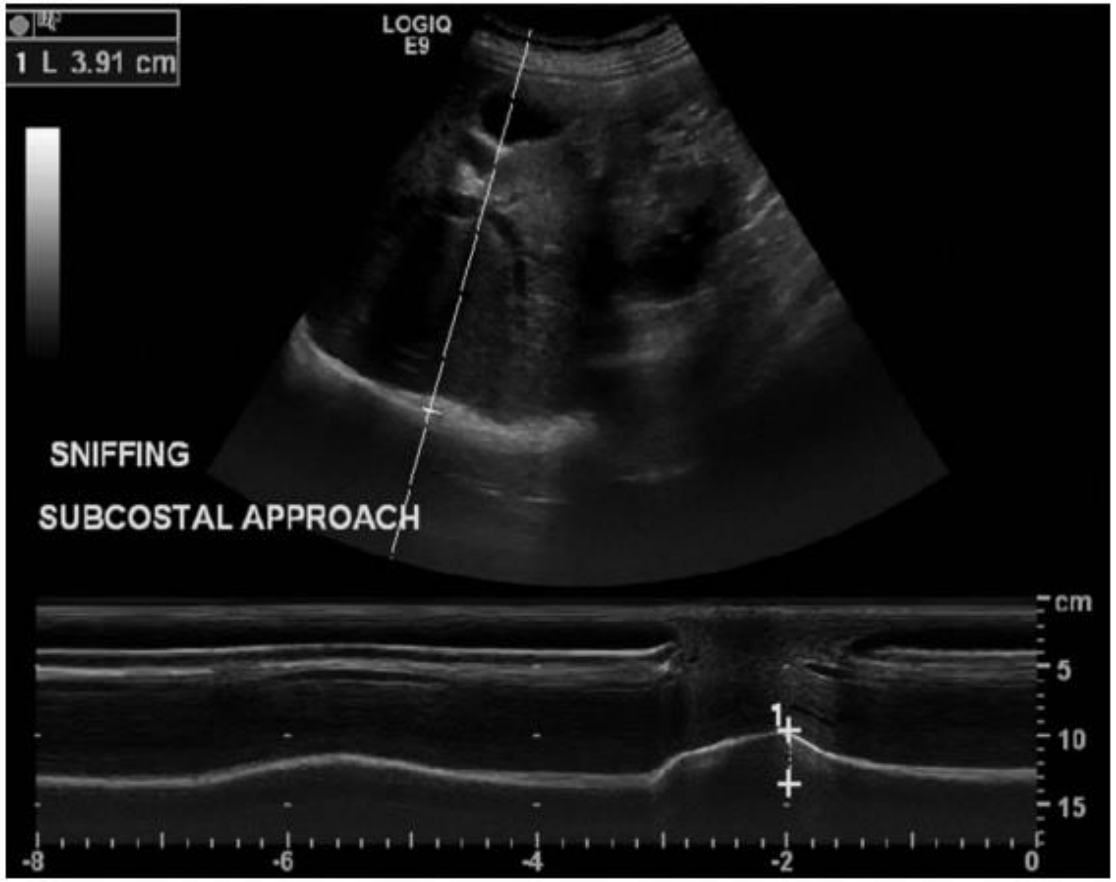
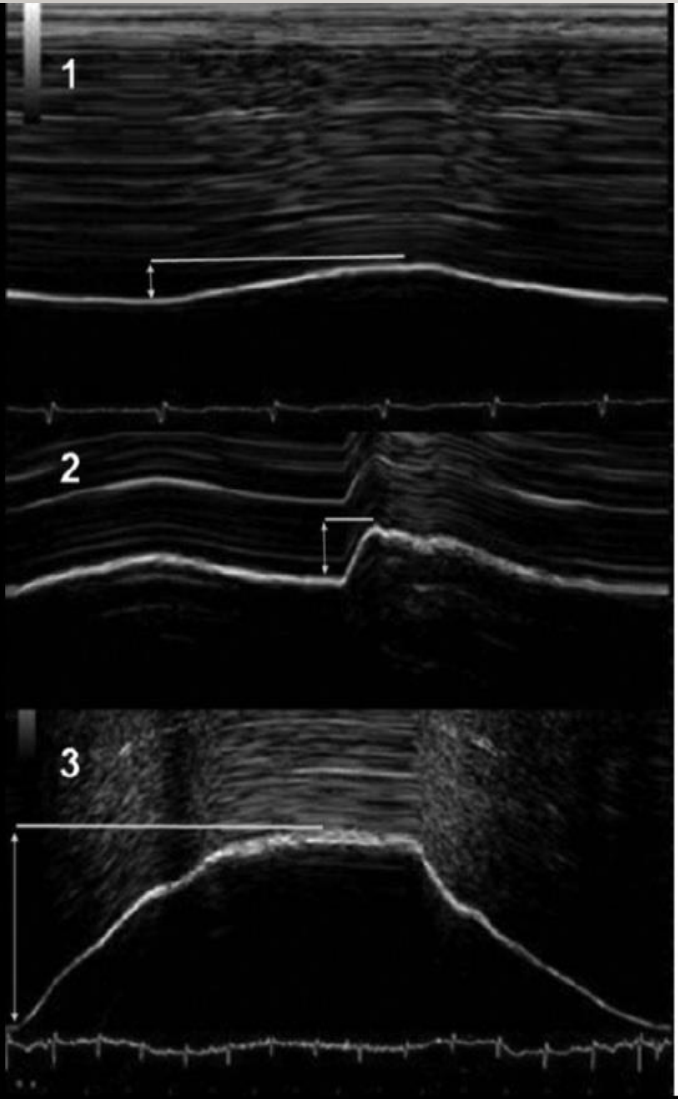


Fig. 4: Diaphragmatic excursion with sniffing (3.91 cm). A curvilenar 4MHz frequency probe was used with a subcostal approach.
References: - /PT

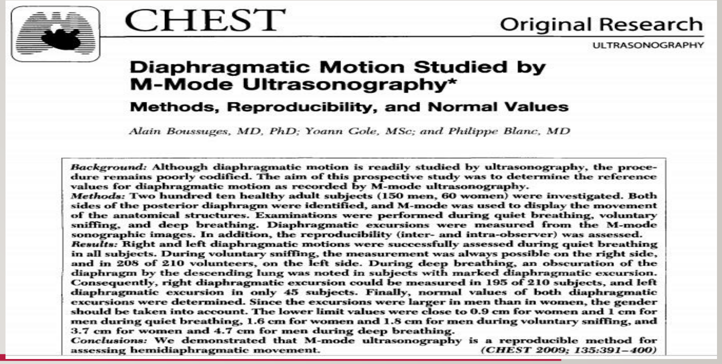


Maneuver began at the end of normal expiration:

Quiet Breathing (QB):
Diaphragm excursion 1.5-2 cm
Lower limit 0.9 cm for women and 1 cm for men

Voluntary Sniffing (VS)
Diaphragm excursion 2.5-3 cm
Lower limit 1.6 cm in women and 1.8 cm in men
“normal caudal movement of the diaphragm during inspiration”

Deep Breathing (DB)
Diaphragm excursion 6-7 cm
Lower limit 3.7 cm for women and 4.7 cm for men



CHEST Original Research
ULTRASONOGRAPHY

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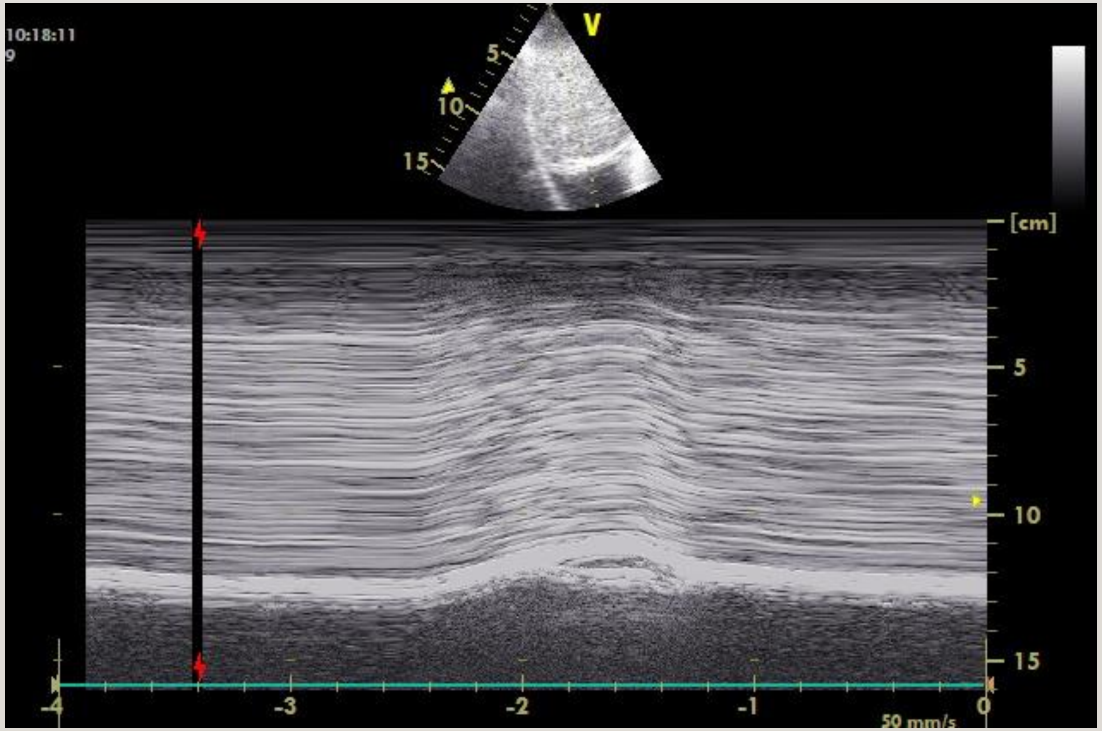
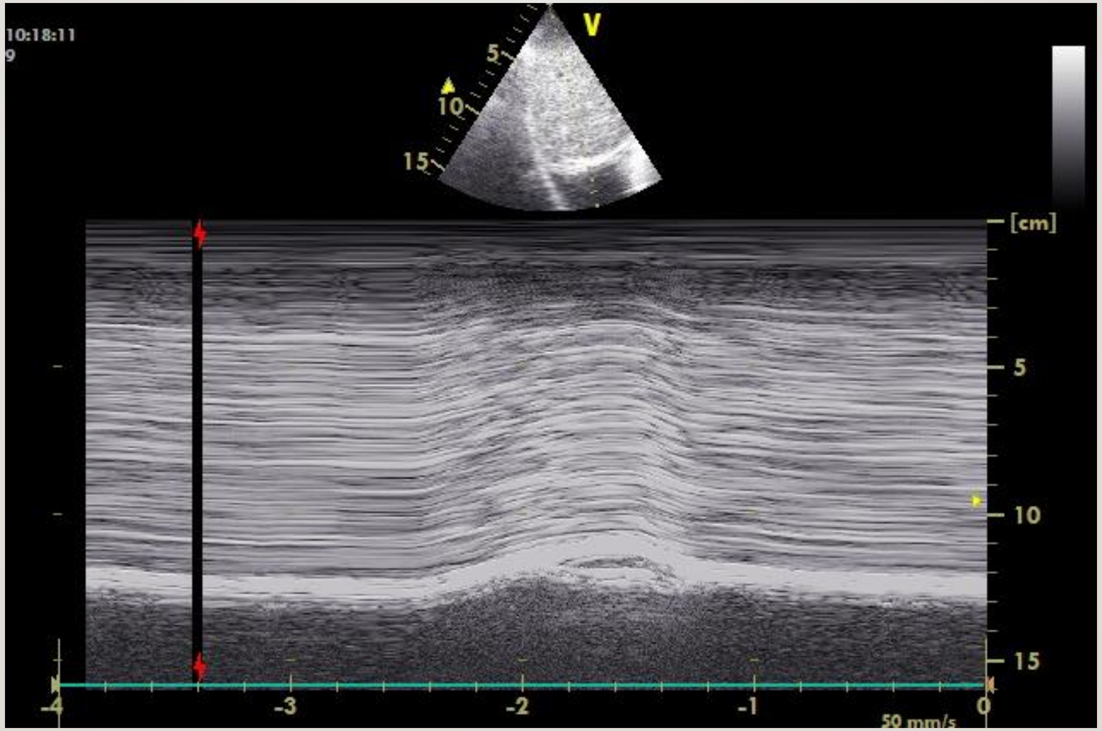
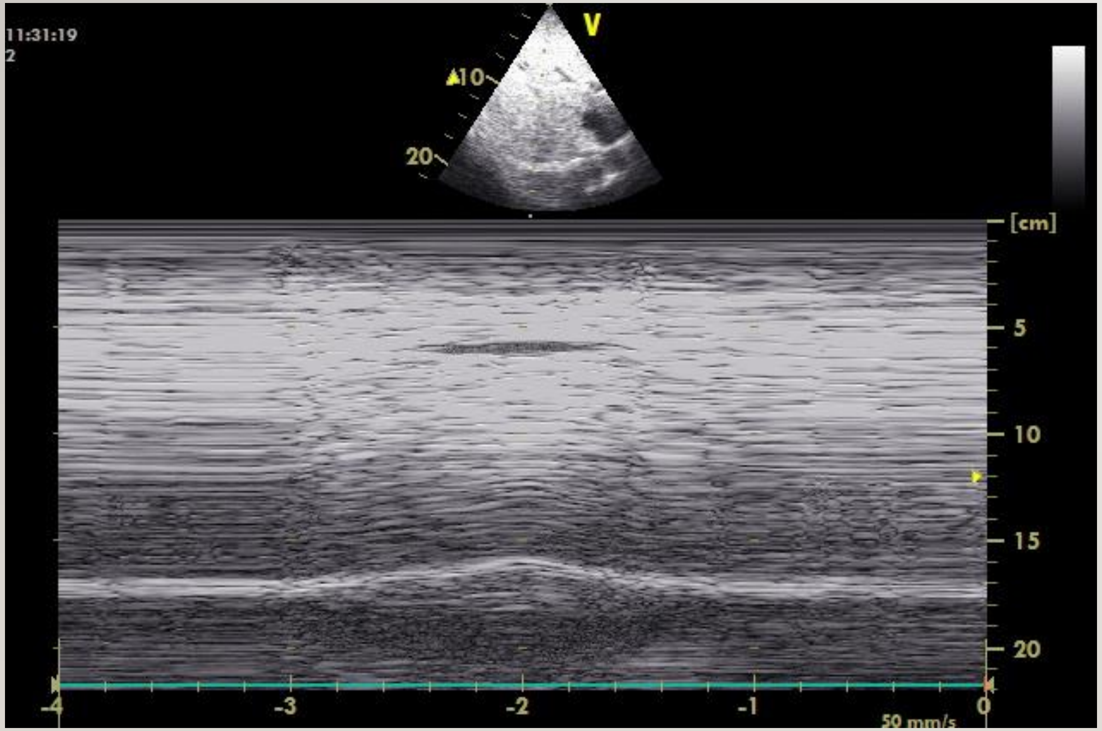
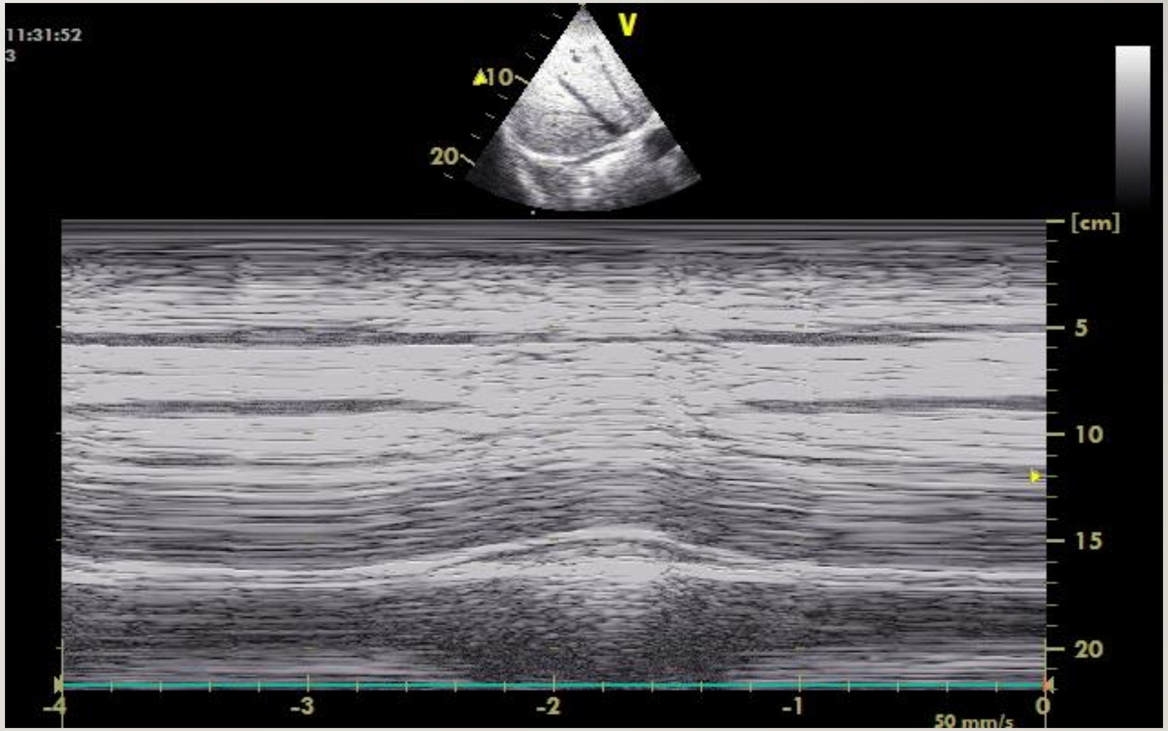


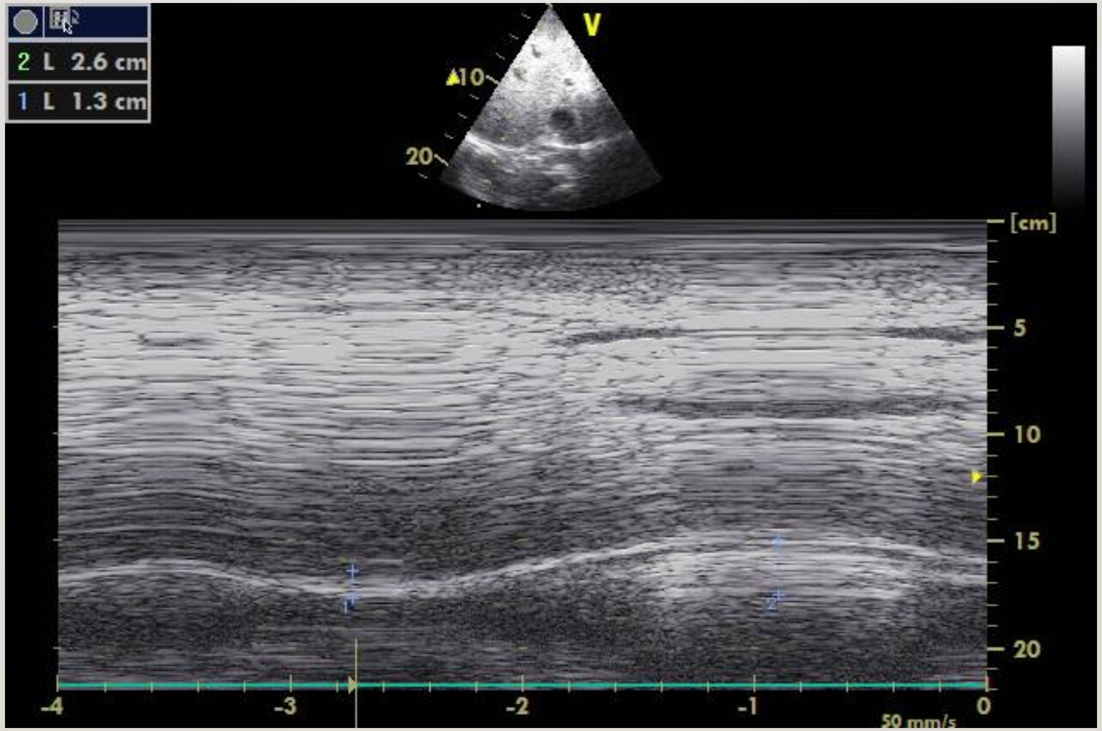
10:18:11
V
5
10
15
[cm]
5
10
15
-4
-3
-2
-1
0
50 mm/s

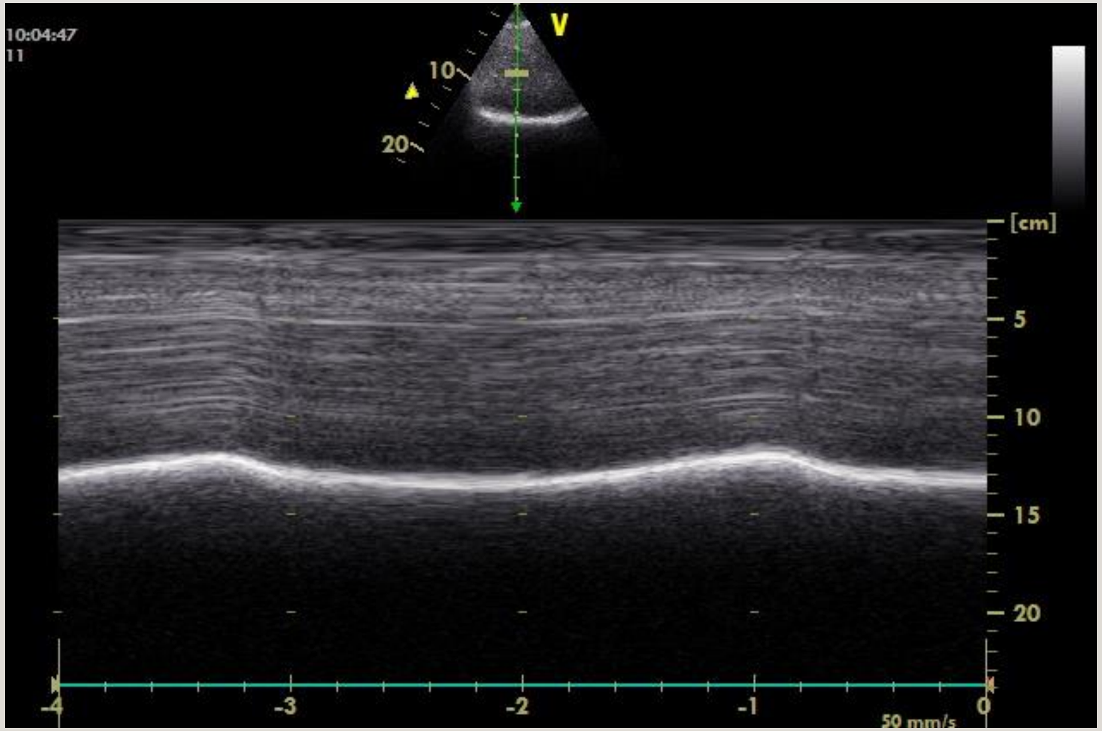


10:18:11
V
5
10
15
[cm]
5
10
15
-4
-3
-2
-1
0
50 mm/s


11:31:19
2
V
10
20
[cm]
5
10
15
20
-4
-3
-2
-1
0
50 mm/s


11:31:52
3
V
10
20
[cm]
5
10
15
20
-4
-3
-2
-1
0
50 mm/s


2 L 2.6 cm
1 L 1.3 cm
V
10
20
[cm]
5
10
15
20
-4
-3
-2
-1
0
50 mm/s


10:04:47
11
V
10
20
[cm]
5
10
15
20
-4
-3
-2
-1
0
50 mm/s

WEAKNESS

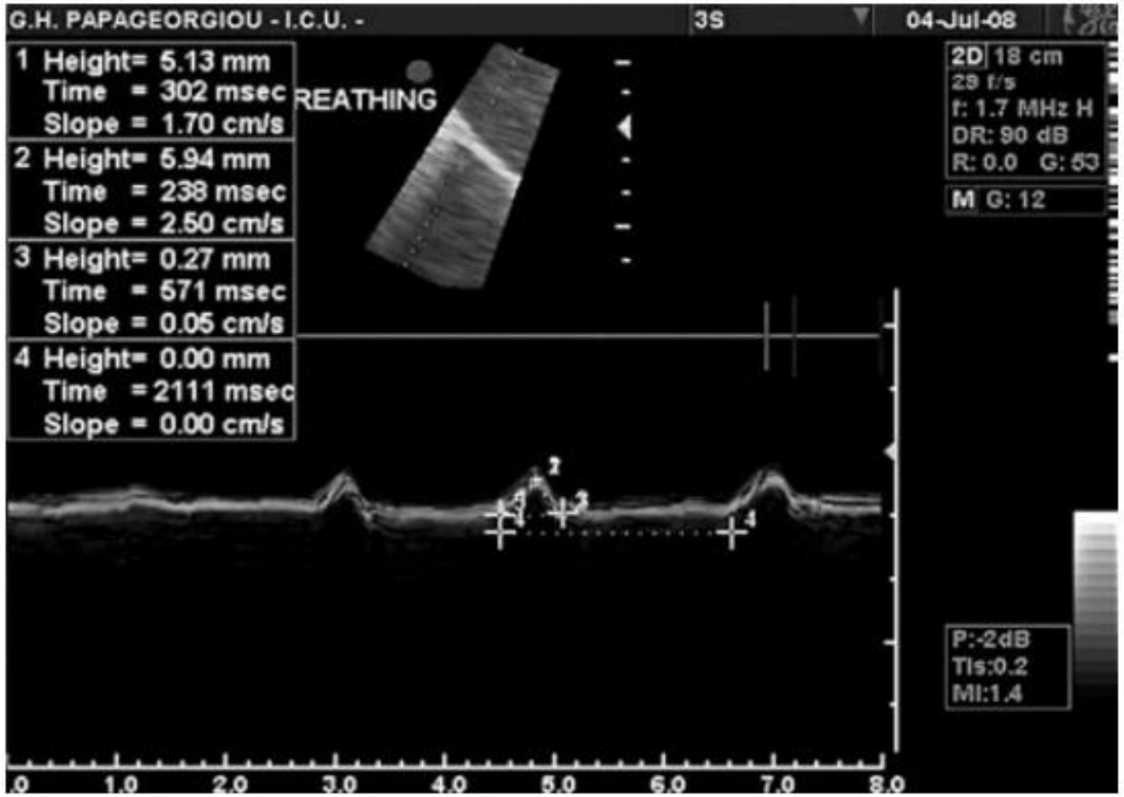


Fig. 9 Diaphragmatic contraction in M-mode sonography during a spontaneous breathing trial in a patient suffering from critical illness neuromyopathy (the *scale* at the *bottom* represent time in seconds). Diaphragmatic weakness is evidenced by the very small diaphragmatic displacement (0.5 cm)

ΠΑΡΑΔΟΞΗ ΚΙΝΗΤΙΚΟΤΗΤΑ

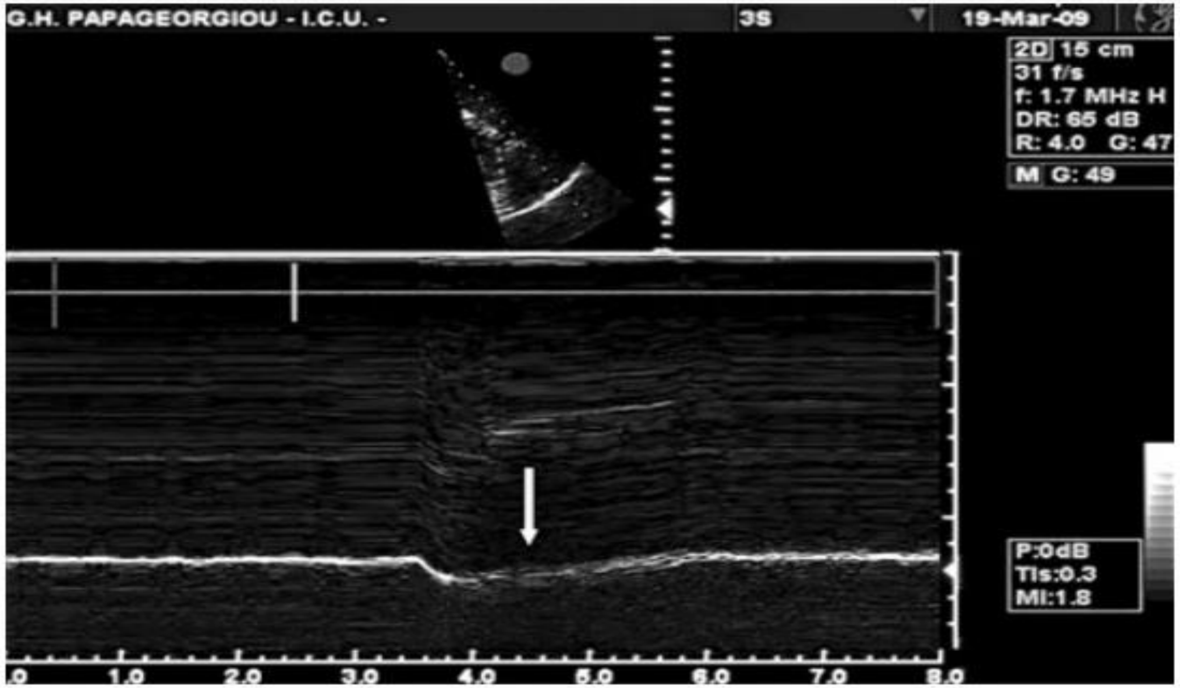
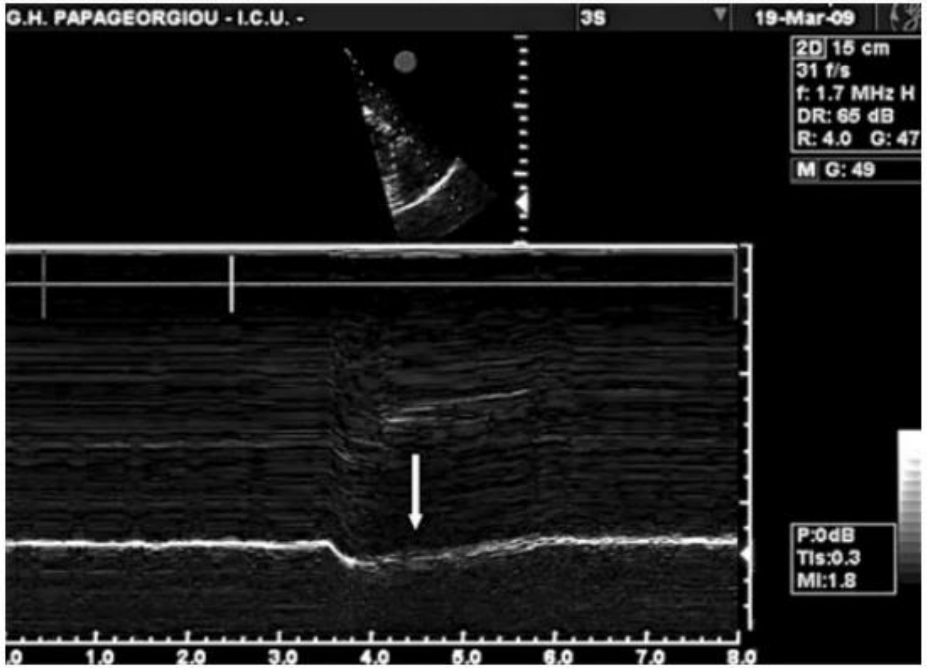


Fig. 7 Paradoxical diaphragmatic motion on M-mode sonography in a patient with Guillain-Barré syndrome (the *scale* at the *bottom* represents time in seconds). There is a cranial diaphragmatic movement (away from the probe) during spontaneous breathing due to diaphragmatic paralysis. The intercostal muscles recover earlier than the diaphragm and create a negative intrathoracic pressure which displaces the paralytic diaphragm inwards, into the thorax and away from the probe



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Intensive Care Med (2013) 39:801–810
DOI 10.1007/s00134-013-2823-1

REVIEW

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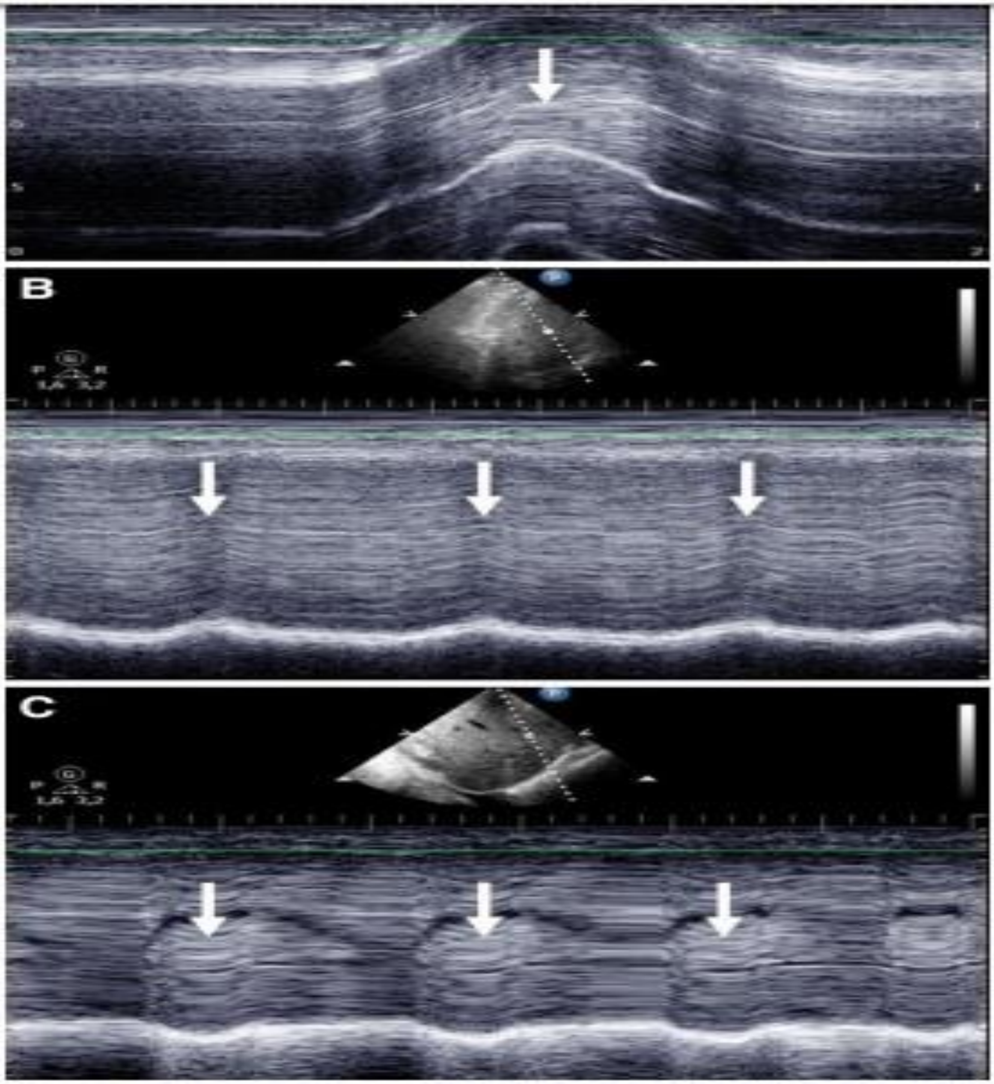
Sonographic evaluation of the diaphragm in critically ill patients. Technique and clinical applications



ig. 1 Diaphragmatic excursions during unassisted deep breathing (*arrows*) in TM mode
a healthy volunteer with normal diaphragmatic excursion, **b** patient with diaphragmatic
aresis and diaphragmatic excursion of less than 10 mm, **c** patient with diaphragmatic
aralysis and a paradoxical movement of the hemidiaphragm

Intensive Care Med (2015) 41:557–559
DOI 10.1007/s00134-014-3636-6

Xavier Valette
Amélie Seguin
Cédric Daubin
Jennifer Brunet
Bertrand Sauneuf
Nicolas Terzi
Damien du Cheyron

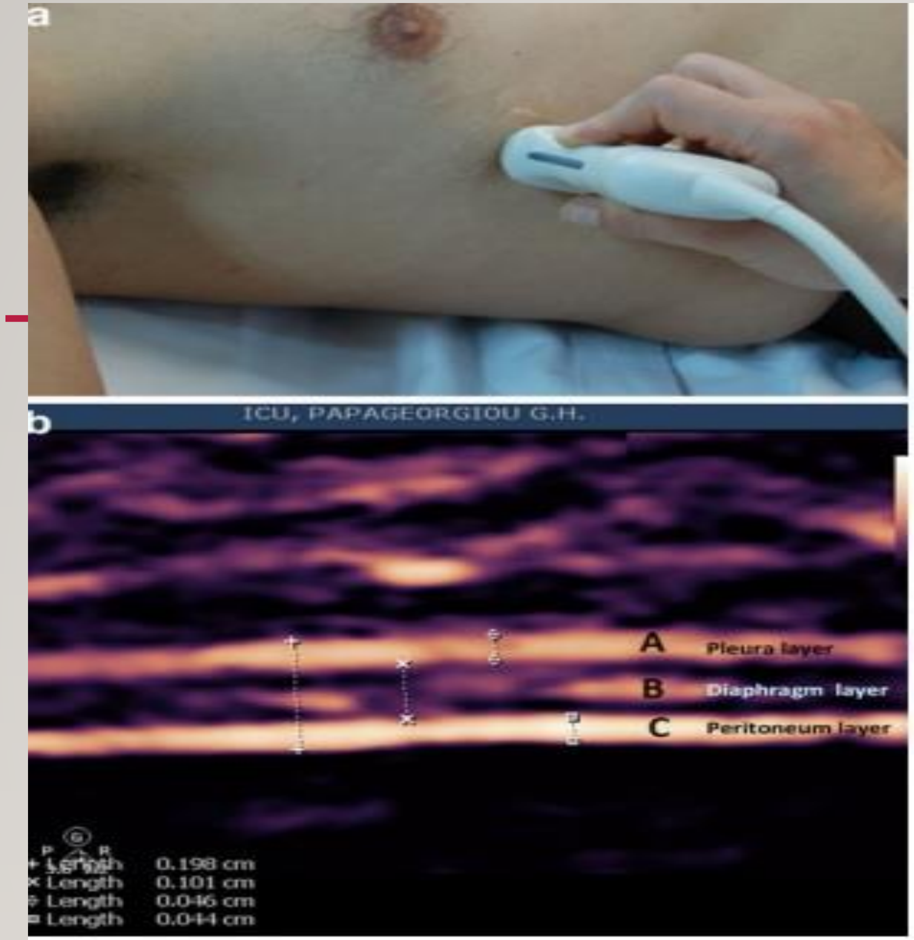
Diaphragmatic dysfunction at admission in intensive care unit: the value of diaphragmatic ultrasonography

- Diaphragmatic excursion depends on the maximal voluntary inspiratory effort of patients
- and is influenced by the position of the subject, being greater in the supine position than in the sitting position for the same inspiratory volume
- Diaphragm motion is affected by the abdominal contents and pressure that limit diaphragm displacement

THICKNESS

στο 9ο-10ο μεσοπλεύριο διάστημα
στη μέση ή πρόσθια μασχαλιαία γραμμή ,
κάθετα στο θωρακικό τοίχωμα ,
στη ζώνη μετάπτωσης (apposition zone)

- The diaphragm Is located by placing the transducer in the intercostal space above the right 10th rib in the midaxillary or anteroaxillary line and directing the ultrasound beam perpendicular to the diaphragm



g. 2 **a** Probe position for B and M mode diaphragmatic thickness easurements in the zone of apposition with 10–12 MHz probe. B-mode sonography of the diaphragm in the zone of apposition. Echogenic diaphragmatic pleura, *B* non-echogenic central layer, echogenic peritoneal layer. Notice the thickness measurement of ch layer

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REVIEW

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Sonographic evaluation of the diaphragm in critically ill patients. Technique and clinical applications

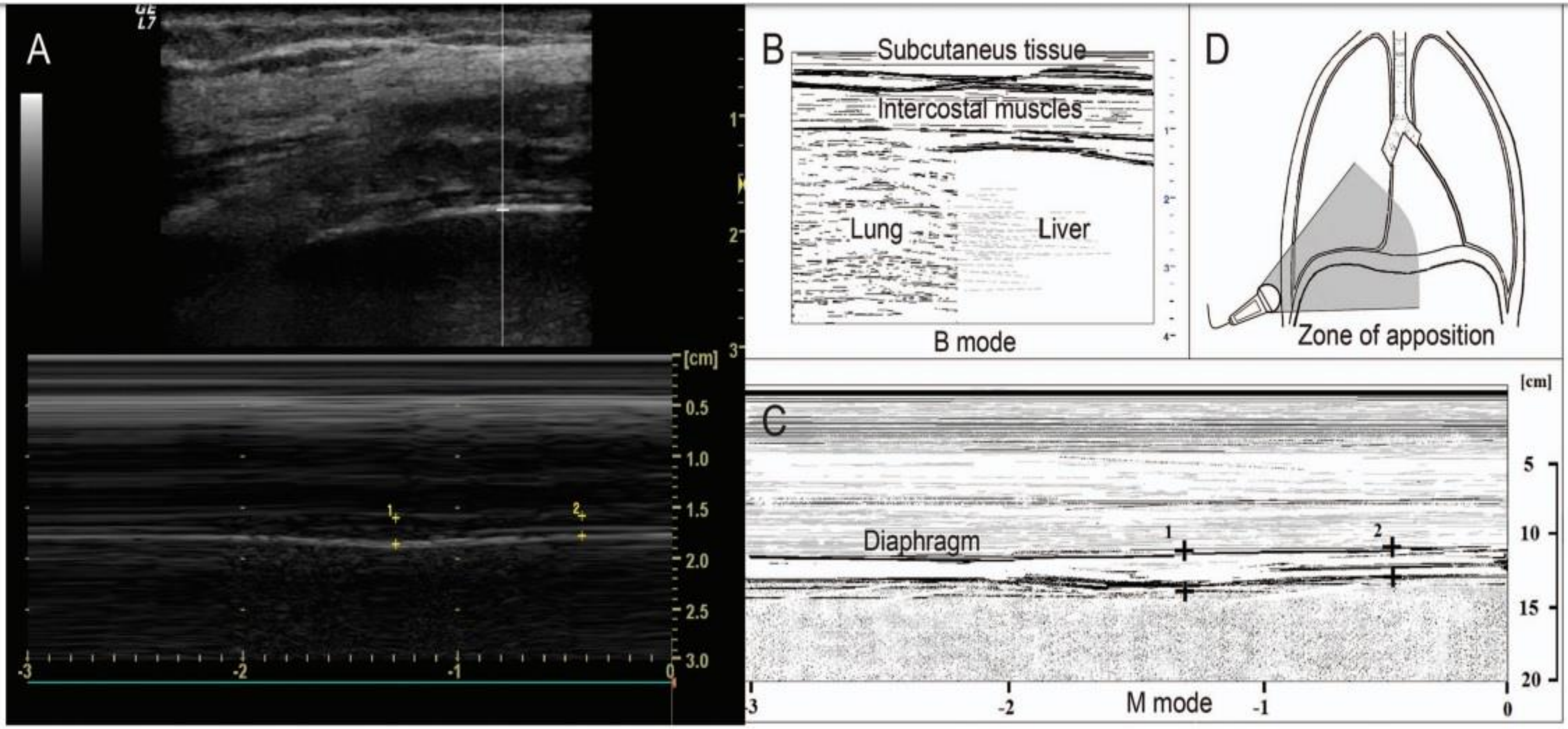


Fig. 3. Ultrasonographic assessment of diaphragm thickness. A: Ultrasonographic view of the normal diaphragm in the zone of apposition, with B-mode in the upper part and M-mode in the lower part. B: Anatomical structures that can be identified in B-mode scanning. C: Anatomical structures that can be identified in M-mode scanning. D: Probe placement to explore the diaphragm in the zone of apposition. The distance identified by plus signs 1 in A and C is end-inspiratory thickness, whereas the distance between plus signs 2 in the same panels is the end-expiratory thickness.

Ultrasonographic Assessment of Diaphragm Function in Critically Ill Subjects

Michele Umbrello MD and Paolo Formenti MD

RESPIRATORY CARE • APRIL 2016 VOL 61 NO 4

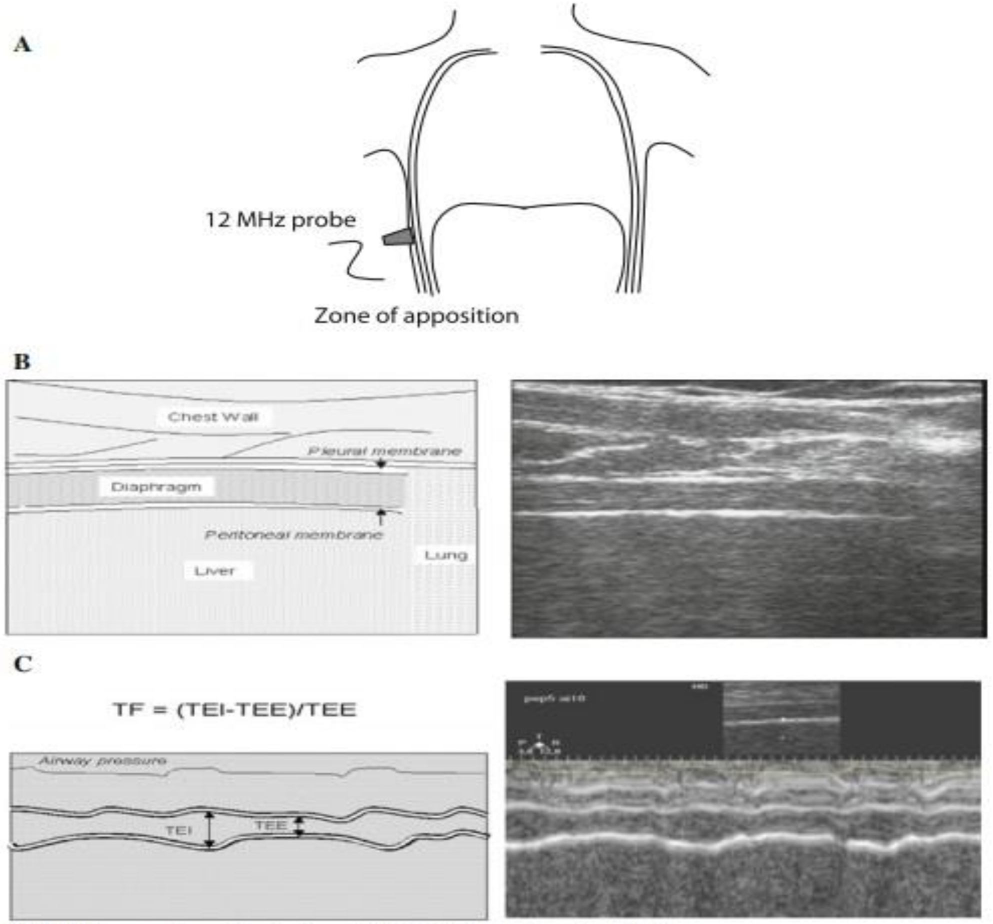


Fig. 1 Probe placement to explore the diaphragm in the zone of apposition (**a**), with the ultrasonographic view of the normal diaphragm in the zone of apposition (**b**) and illustration of the measurement of diaphragm thickness at end-inspiration and end-expiration in TM mode (**c**). T_{EI} thickness at end-inspiration, T_{EE} thickness at end-expiration

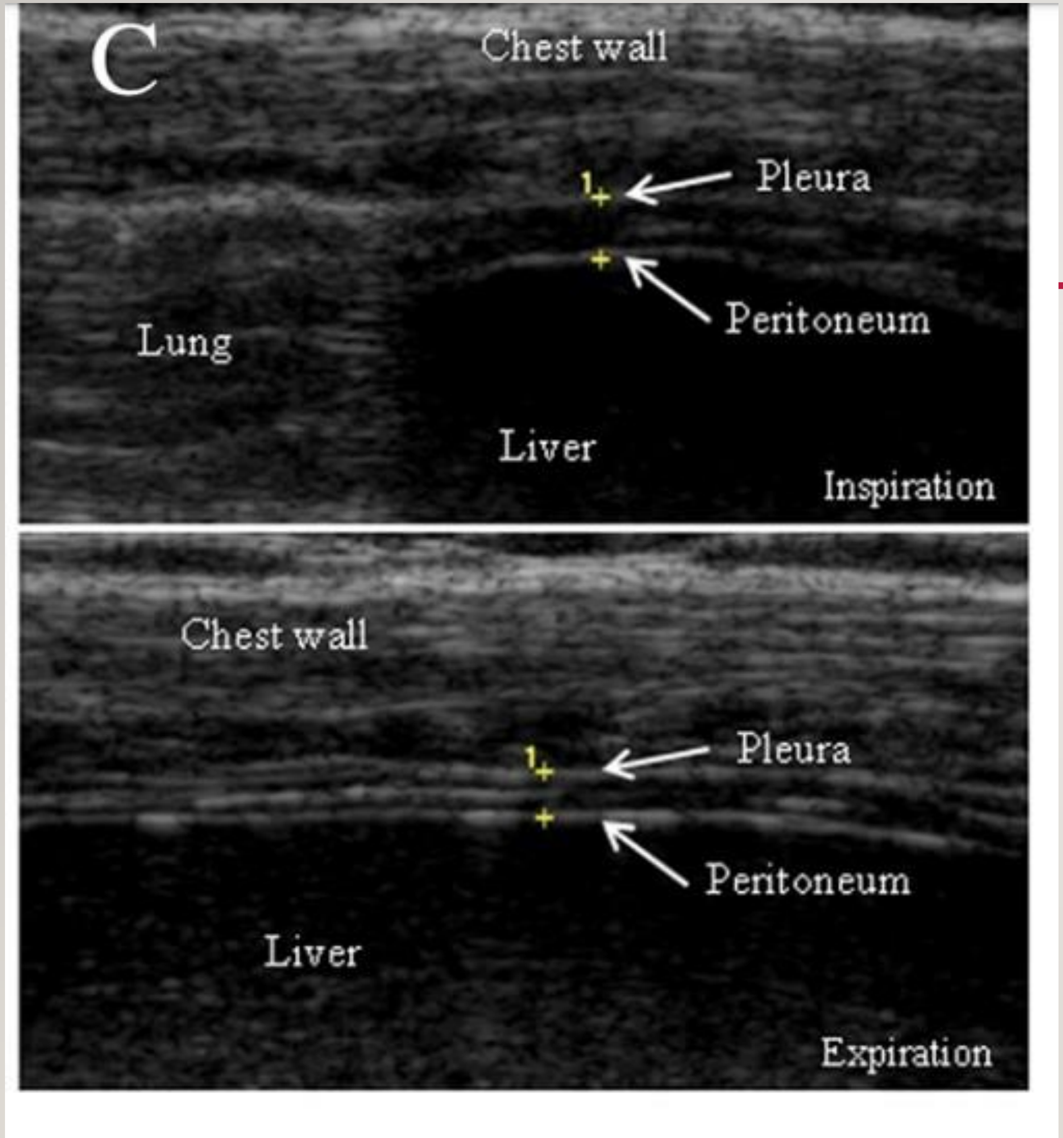
TEI, thickness at end inspiration; TEE, thickness at end expiration.

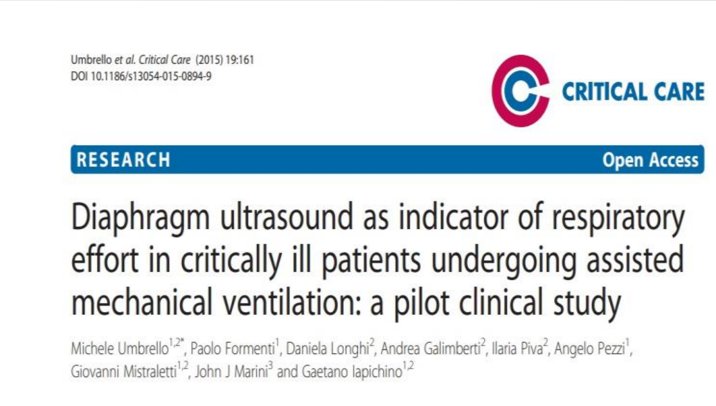
Intensive Care Med (2012) 38:796–803
DOI 10.1007/s00134-012-2547-7

ORIGINAL

Emmanuel Vivier
Armand Mekontso Dessap
Saoussen Dimassi
Frederic Vargas
Aissam Lyazidi
Arnaud W. Thille
Laurent Brochard

Diaphragm ultrasonography to estimate the work of breathing during non-invasive ventilation





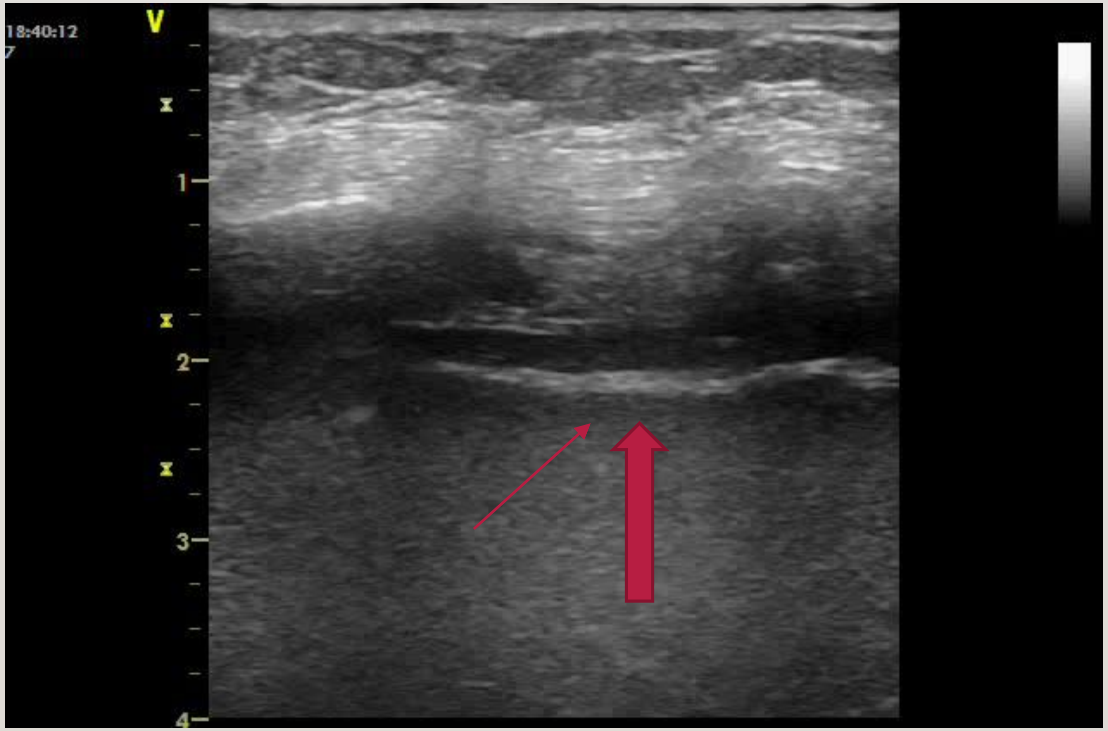
Umbrello *et al. Critical Care* (2015) 19:161
DOI 10.1186/s13054-015-0894-9

CRITICAL CARE

RESEARCH Open Access

Diaphragm ultrasound as indicator of respiratory effort in critically ill patients undergoing assisted mechanical ventilation: a pilot clinical study

Michele Umbrello[1,2*], Paolo Formenti[1], Daniela Longhi[2], Andrea Galimberti[2], Ilaria Piva[2], Angelo Pezzi[1], Giovanni Mistraletti[1,2], John J Marini[3] and Gaetano Iapichino[1,2]



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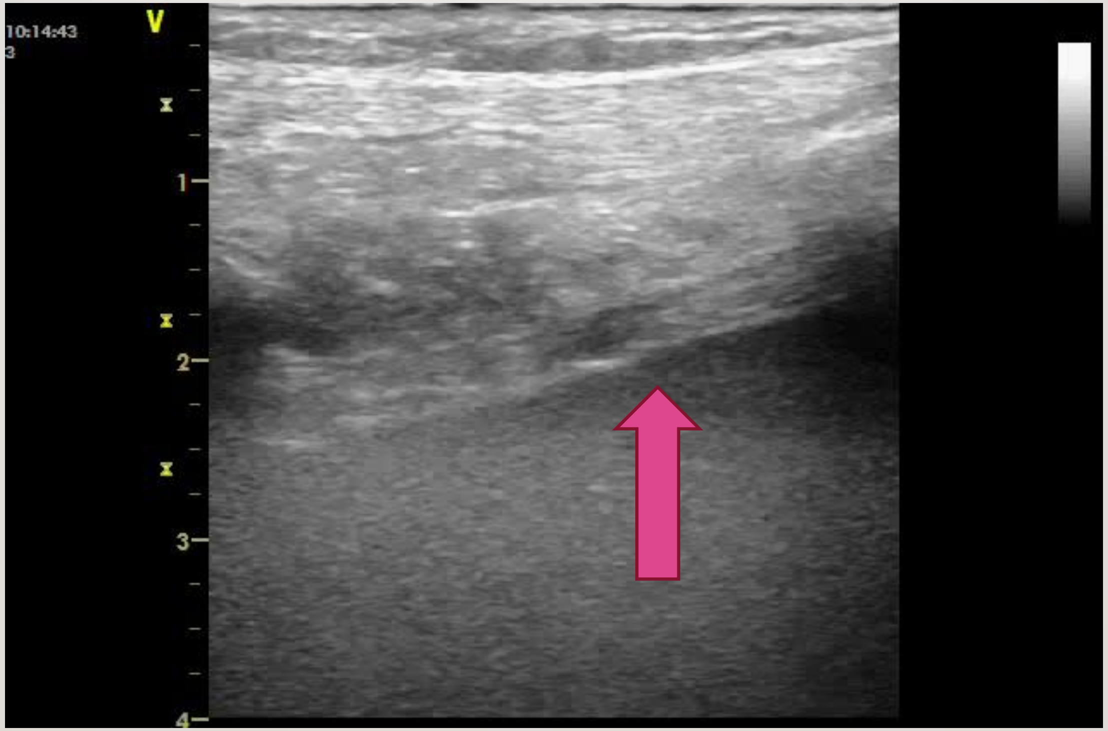
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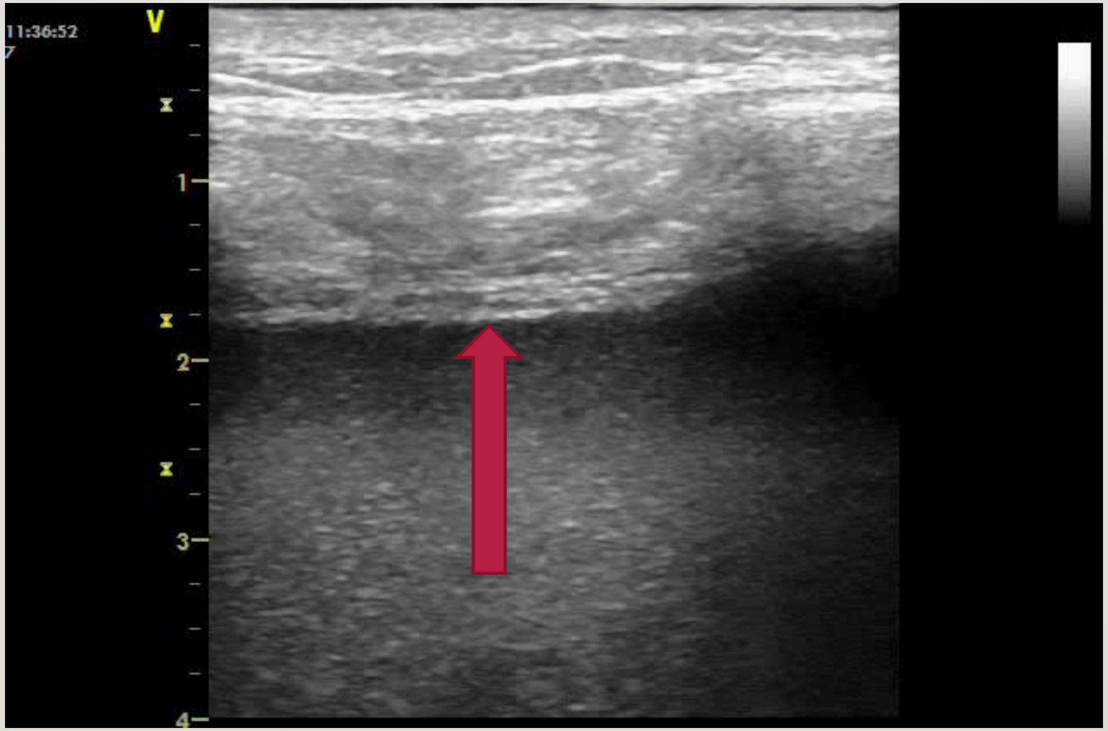
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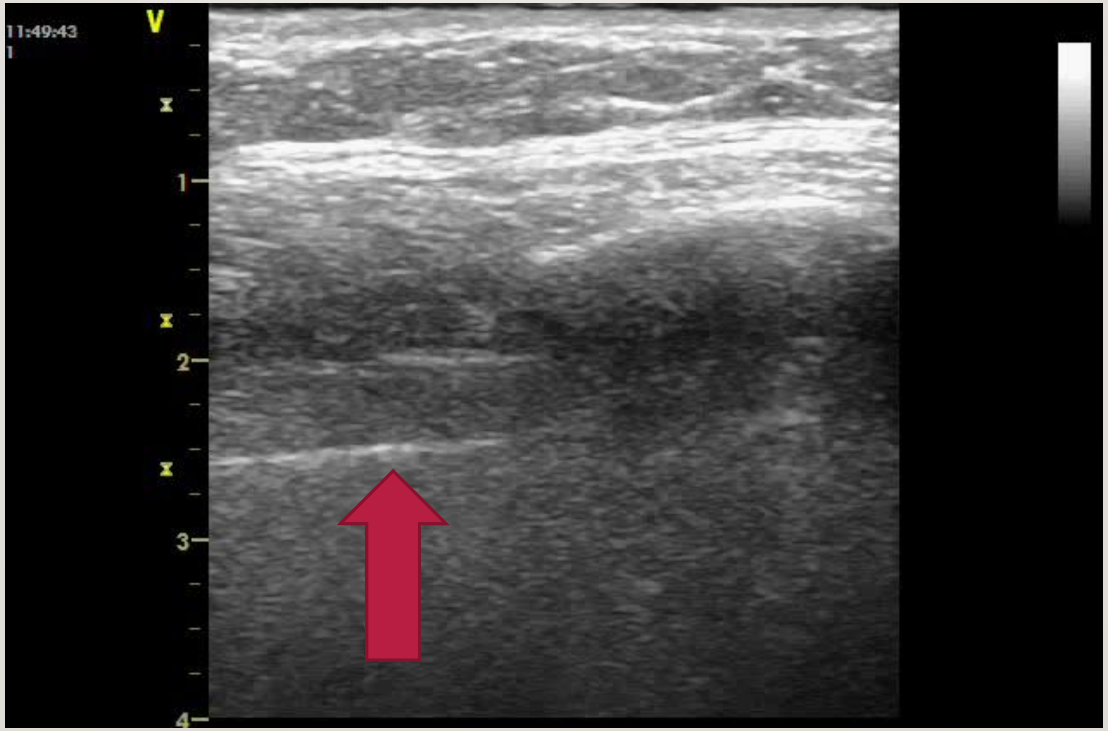
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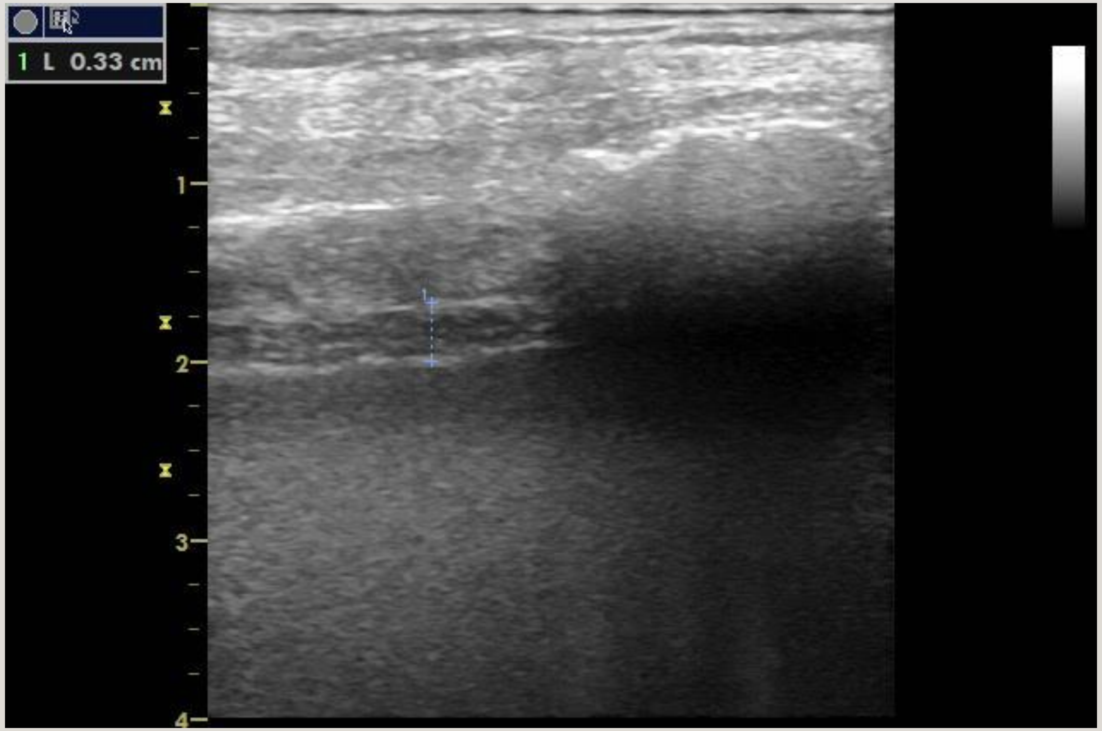
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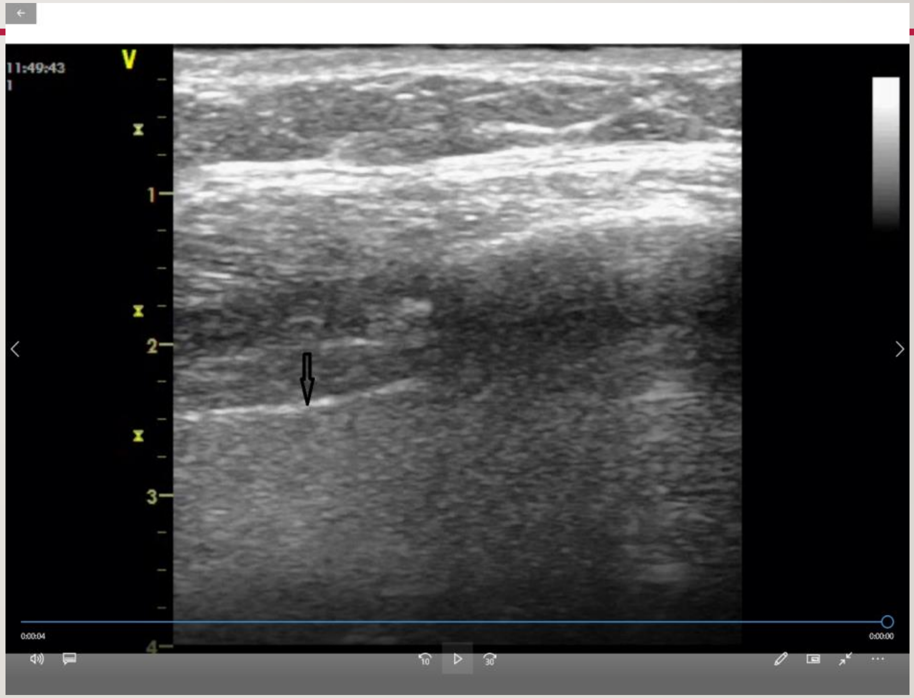
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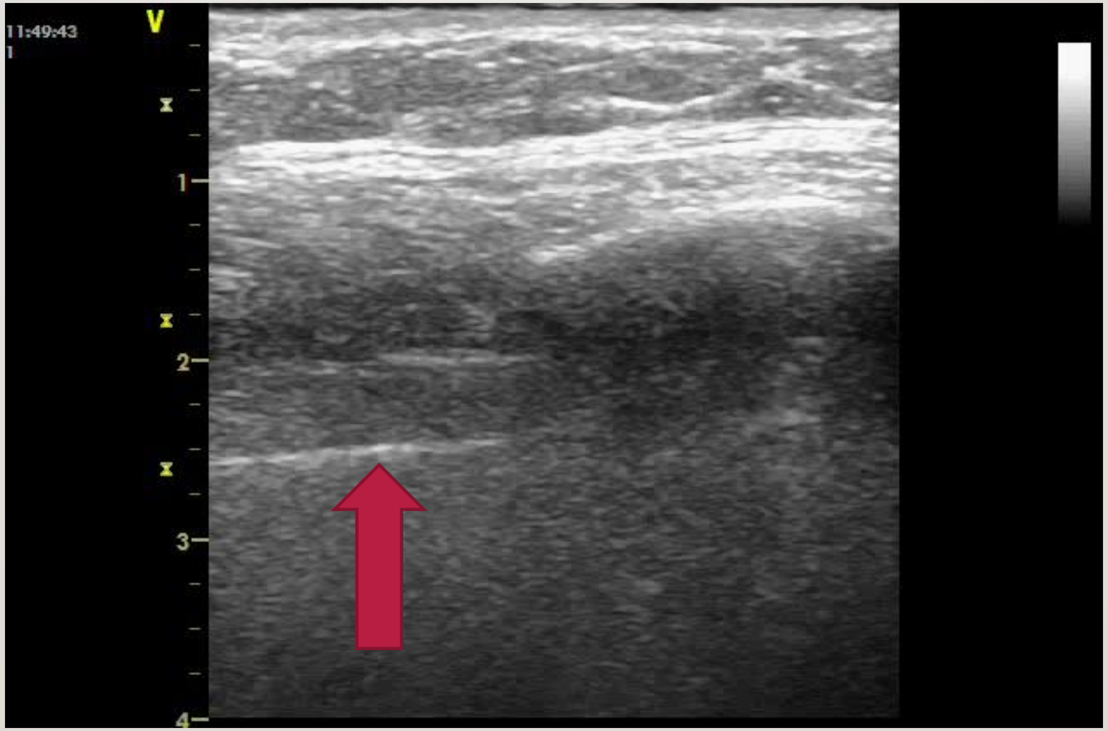
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NORMAL VALUES

- Normal values of diaphragmatic thickness:
- In normal individuals, there is a wide range of diaphragmatic thickness at functional residual capacity (FRC), ranging between 1.8 to 3 mm

Diaphragm thickness from apposition zone ultrasound	
Diaphragmatic thickness value = 2.2+–0.4 mm at FRC	Wait et al. [4] N = 10 male volunteers
Mean diaphragmatic thickness = 1.7 +–0.2 mm at FRC = 1.6 +–0.2 mm at residual volume	Ueki et al. [5] N = 13 healthy men
Mean Right diaphragm thickness at FRC = 3.3+–1 mm Mean Left diaphragmatic thickness at FRC = 3.4+–1.8 mm Mean Right diaphragm thickness at FRC in men = 3.8+–1.5 mm Mean Right diaphragm thickness at FRC in women = 2.7+–1 mm Right TR: 1.8+–0.5 Left TR: 1.9+–0.6	Boon *AJ* et al. [7] N = 150 normal subjects
Mean expiratory diaphragm thickness **Female:** 1.4+–0.3 mm **Male:** 1.9+–0.4 mm	Raul carrillo-Esper et al. [66] N = 109 normal subjects

FRC: functional residual capacity. N: number of patients. TR: thickening ratio = diaphragm thickness at maximum inspiration/diaphragm thickness at end expiration.

Journal of Neuromuscular Diseases 5 (2018) 1–10
DOI 10.3233/JND-170276
IOS Press

Review

Diaphragm: Pathophysiology and Ultrasound Imaging in Neuromuscular Disorders

Abdallah Fayssoil[a,b,*], Anthony Behin[b], Adam Ogna[c], Dominique Mompoint[a], Helge Amthor[a,d], Bernard Clair[a], Pascal Laforet[b,d], Arnaud Mansart[a], Helene Prigent[a,d], David Orlikowski[a], Tanya Stojkovic[b], Stéphane Vinit[d], Robert Carlier[a,d], Bruno Eymard[b], Frederic Lofaso[a,d] and Djillali Annane[a]

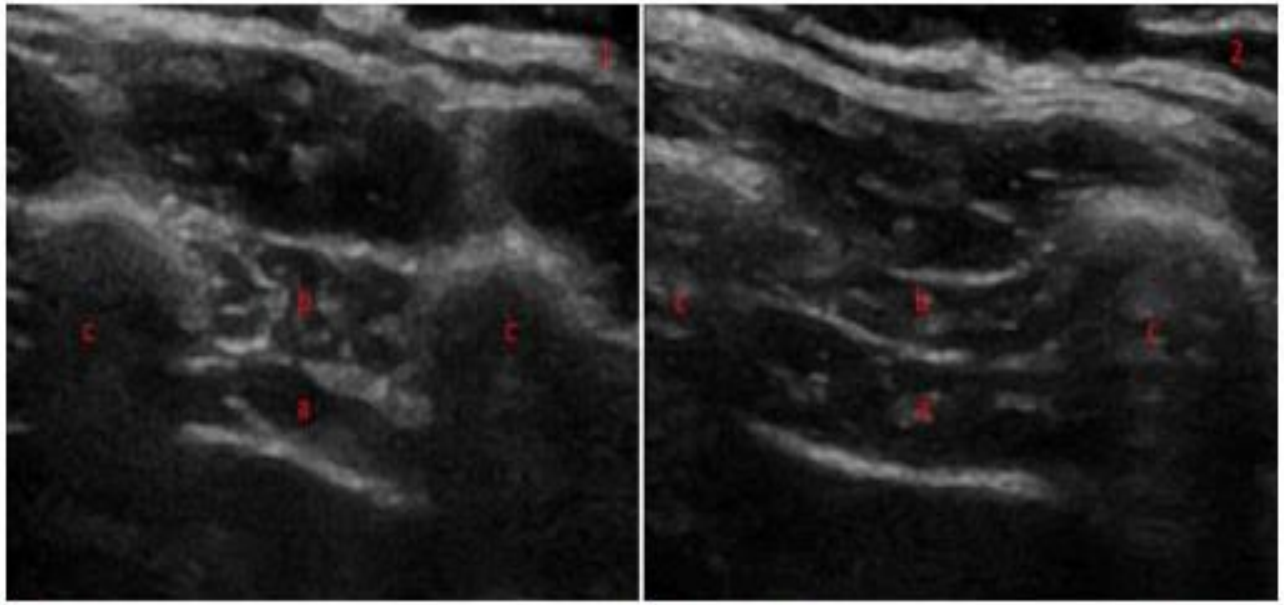


Fig. 4 Diaphragm thickness in B-mode thoracic view at end expiration (1) and inspiration (2) in a heathy volunteer. The diaphragm can be seen between two echogenic layers (a) with the intercostal compartment above (b). The two muscle layers sit between two ribs (**c**)

Turton *et al. Ultrasound J* (2019) 11:2
https://doi.org/10.1186/s13089-019-0117-8
The Ultrasound Journal
REVIEW Open Access

A narrative review of diaphragm ultrasound to predict weaning from mechanical ventilation: where are we and where are we heading?

Peter Turton[1,2*], Sondus ALAidarous[1,3] and Ingeborg Welters[1,2]

- As lung volume increases from the residual volume (RV) to total lung capacity (TLC) there is a mean diaphragmatic thickness(tdi) increase of 54 % (range 42–78 %).
- Diaphragm muscle thickness depends on lung volumes and normally increases during inspiration
- Diaphragmatic thickness in the zone of apposition increases during a maximal inspiratory maneuver with good correlation between diaphragm thickening ratio and maximal inspiratory pressure

Theerawit *et al. BMC Pulmonary Medicine* (2018) 18:175
https://doi.org/10.1186/s12890-018-0739-9
BMC Pulmonary Medicine

RESEARCH ARTICLE Open Access

Diaphragmatic parameters by ultrasonography for predicting weaning outcomes

Pongdhep Theerawit[1], Dararat Eksombatchai[2], Yuda Sutherasan[2*], Thitiporn Suwatanapongched[3], Charn Kiatboonsri[2] and Sumalee Kiatboonsri[2]

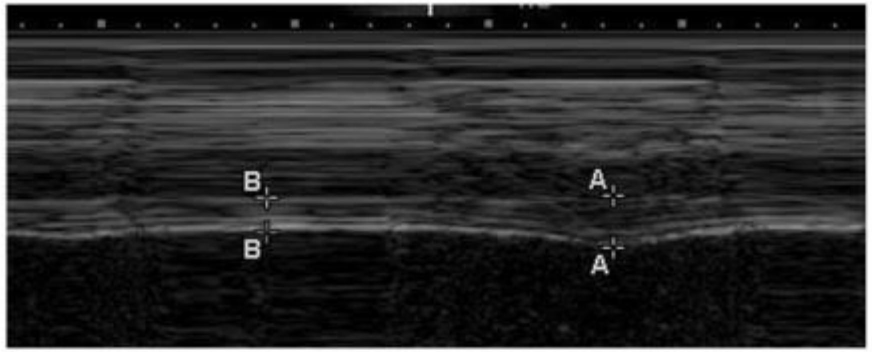


Fig. 2 Image illustrating the part of the diaphragm at the area of apposition for measurement of the diaphragmatic thickness (DT). The A-A is the DT at end inspiration, and the B-B is the DT at end expiration

ΔΕΞΙΟ- ΑΡΙΣΤΕΡΟ ΗΜΙΔΙΑΦΡΑΓΜΑ

Table 2 comparison between right and left diaphragmatic parameters

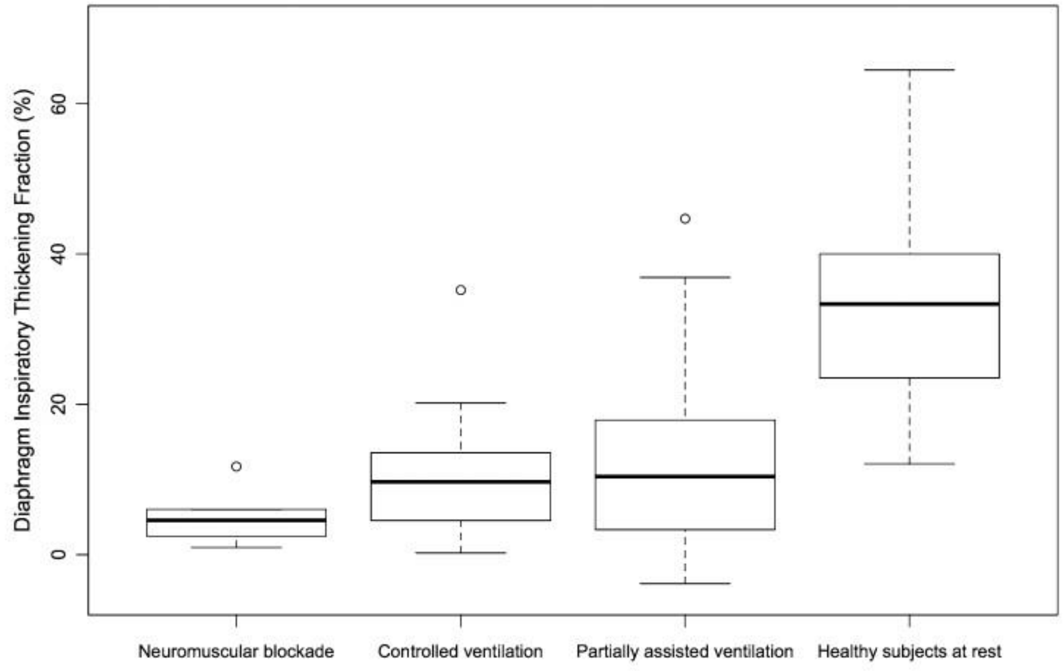
Ultrasonographic parameters	Right	Left	*P* value
Diaphragmatic inspiratory excursion (mm.)	13.5 ± 6.5	13.4 ± 6.2	0.87
$TPIA_{dia}$ (second)	1.2 ± 0.40	1.1 ± 0.39	0.08
Inspiratory DT (mm.)	3.8 ± 1.0	3.8 ± 1.0	0.33
Expiratory DT (mm.)	2.8 ± 0.7	2.8 ± 0. 6	0.52
DTD (mm.)	9.8 ± 4.9	10.1 ± 5.1	0.51
TFdi (%)	36 ± 17	35 ± 14	0.89

$TPIA_{dia}$ Time to peak inspiratory amplitude of diaphragm, *DT* diaphragmatic thickness, *DTD* Diaphragmatic thickness difference, *TFdi* diaphragm thickening fraction
All data are present as mean ± SD

THICKENING FRACTION

- An index of diaphragmatic thickening, the thickening fraction (TF) can be calculated using the M mode
- (TF = thickness at end inspiration - thickness at end-expiration/thickness at end-expiration).
- Diaphragmatic thickening fraction can be used as an index of diaphragmatic efficiency as a pressure generator

Fig. 1 Inspiratory thickening fraction of the right hemidiaphragm in healthy subjects at rest and ventilated subjects under varying conditions. Inspiratory thickening is observed at very low levels in patients subjected to neuromuscular blockade, suggesting that thickening mainly reflects diaphragm contractile activation rather than increases in thoracic volume per se



Intensive Care Med (2015) 41:642–649
DOI 10.1007/s00134-015-3687-3

ORIGINAL

Ewan C. Goligher
Franco Laghi
Michael E. Detsky
Paulina Farias
Alistair Murray
Deborah Brace
Laurent J. Brochard
Steffen Sebastien-Bolz
Gordon D. Rubenfeld
Brian P. Kavanagh
Niall D. Ferguson

Measuring diaphragm thickness with ultrasound in mechanically ventilated patients: feasibility, reproducibility and validity

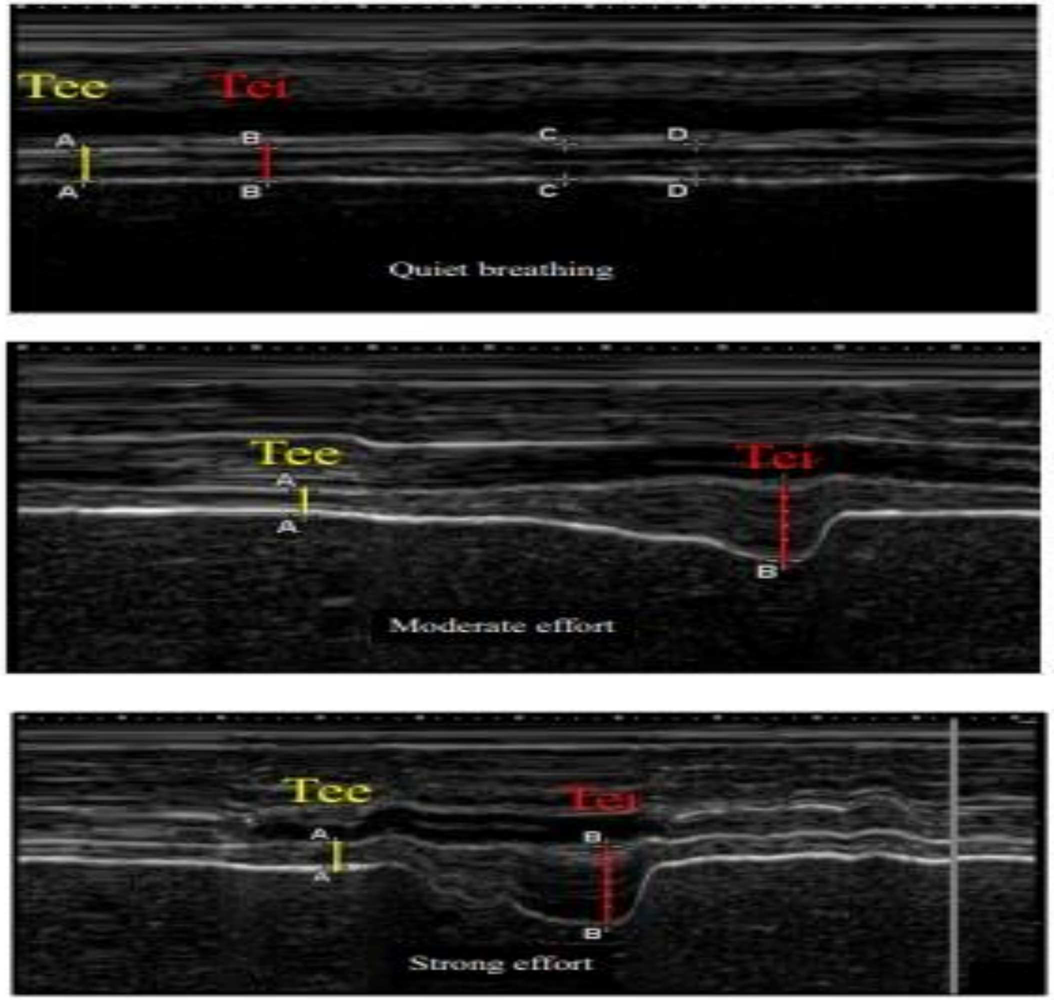


Fig. 2 Diaphragm ultrasound using time-motion mode at three different conditions: quiet breathing, moderate inspiratory effort, and strong inspiratory effort. Note the increase in diaphragm end inspiratory thickness (Tei) at moderate and strong inspiratory effort. *Tee* end expiratory thickness, *Tei* end inspiratory thickness

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REVIEW

Critical illness-associated diaphragm weakness

Martin Dres[1,2,3*], Ewan C. Goligher[4,5], Leo M. A. Heunks[6] and Laurent J. Brochard[3,5]

NORMAL VALUES

- There is a wide range of TF values: it is 0–5% in patients under neuromuscular blockade
- it ranges between 20% and 50% in spontaneously breathing patients after extubation

WEAKNESS

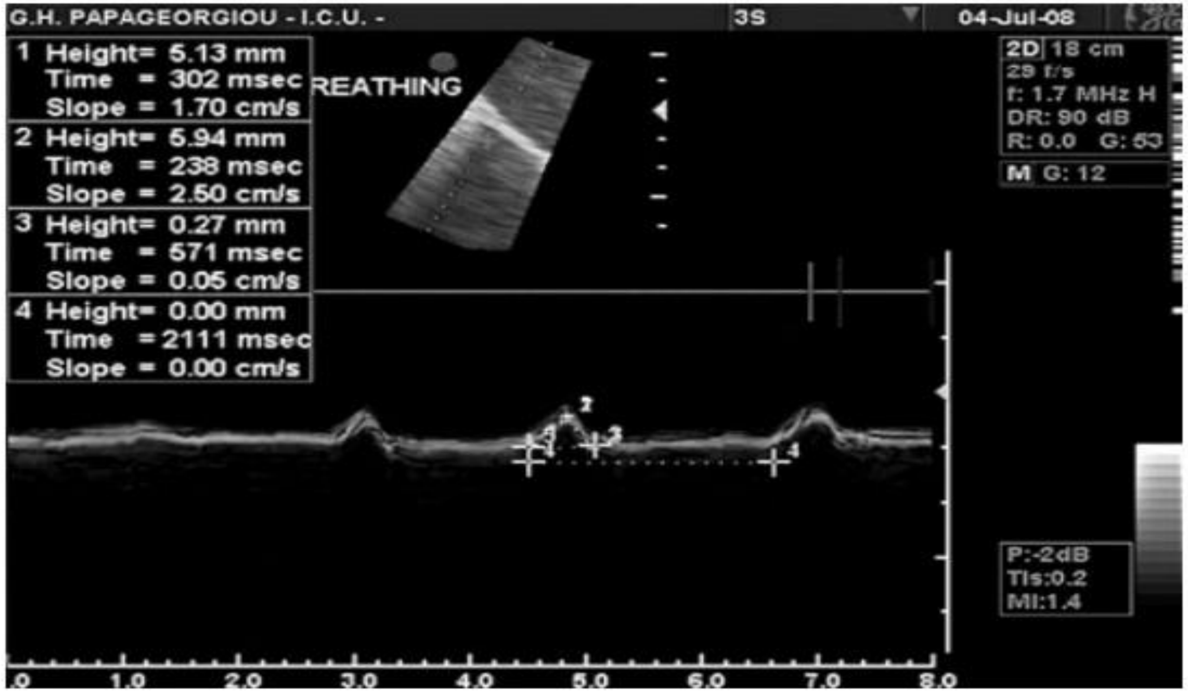
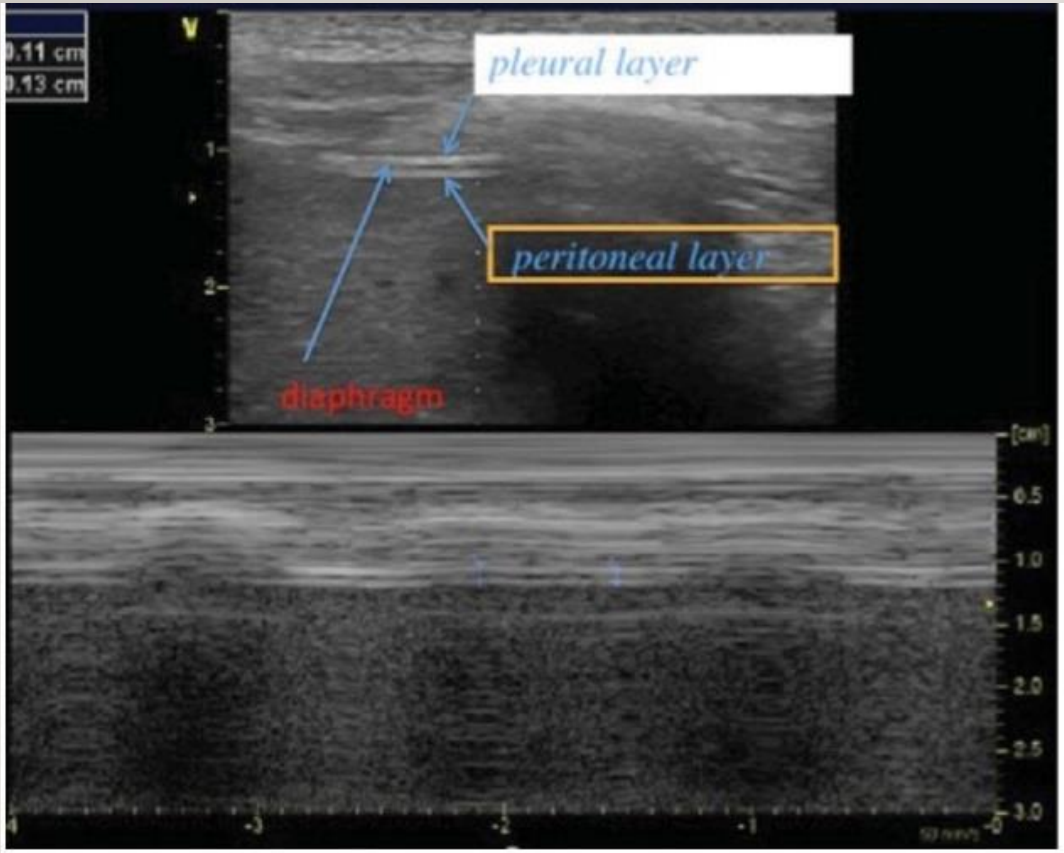


Fig. 9 Diaphragmatic contraction in M-mode sonography during a spontaneous breathing trial in a patient suffering from critical illness neuromyopathy (the *scale* at the *bottom* represent time in seconds). Diaphragmatic weakness is evidenced by the very small diaphragmatic displacement (0.5 cm)



trasound imaging from the zone of apposition for the measurement of diaphragm thickness. The diaphragm is located tal muscles and we can distinguish three layers: a hypo-echogenic thick layer (diaphragm muscle) surrounded by two es (pleural layer and peritoneal layer). Here is a reduced diaphragm thickness (1.3 mm) in a patient with Duchenne

Table 1 Techniques for assessing diaphragm force and activity in critically ill patients

	Markers of		Cutoff defining diaphragm weakness
	Diaphragm activity	Diaphragm force	
Ultrasound			
TFdi			
Requires a high frequency linear probe	Tidal TFdi	TFdimax	<20% [15]
EXdi			
Requires a low frequency abdominal probe Patient disconnected from ventilator	EXdi	Max EXdi	<1 cm [17]
Pressure			
Pdi			
Requires esophageal and gastric balloons	Pdi	Pdimax	Pdimax <60 cmH_2O [8]
Pdi,tw Pet,tw			
Require magnetic stimulation	–	Pdi,tw	<−10 cmH_2O [8]
		Pet,tw	<−11 cmH_2O [9]
ΔPga/ΔPdi			
Incorrect placement of the gastric balloon in the lower esophagus and recruitment of abdominal muscles mimic severe diaphragmatic weakness	–	ΔPga/ΔPdi	<0 [8]
Electromyography			
EMG			
Requires surface electrodes and offline analysis	RMS	–	Not defined
EAdi			
Requires dedicated ventilator	EAdipeak	EAdimax	Not defined

TFdi diaphragm thickening fraction, *EXdi* diaphragm excursion, *Pdi* transdiaphragmatic pressure, *Pdi,max* maximal transdiaphragmatic pressure, *Pet,tw* endotracheal pressure induced by bilateral magnetic stimulation of the phrenic nerves, *Pdi,tw* transdiaphragmatic pressure induced by bilateral magnetic stimulation of the phrenic nerves, *ΔPga/ΔPdi* ratio of the inspiratory Pga swings to Pdi, *EMG* electromyogram, *EAdi* electrical activity of the diaphragm, *RMS* root mean square, *EAdipeak* peak of the EAdi signal, *EAdimax* EAdi during a maximal inspiratory effort

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DOI 10.1007/s00134-017-4928-4

REVIEW

Critical illness-associated diaphragm weakness

Martin Dres[1,2,3*], Ewan C. Goligher[4,5], Leo M. A. Heunks[6] and Laurent J. Brochard[3,5]

DEFINITION OF DIAPHRAGM DYSFUNCTION

- **It has been defined :**
- as a thickening fraction of less than 20%
- or a tidal excursion of less than 10 mm
- or the presence of paradoxical movement in the case of the paralyzed diaphragm

ΚΛΙΝΙΚΕΣ ΕΦΑΡΜΟΓΕΣ

- ΕΚΤΙΜΗΣΗ ΛΕΙΤΟΥΡΓΙΚΟΤΗΤΑΣ ΔΙΑΦΡΑΓΜΑΤΟΣ ΣΤΗ ΜΕΘ (ΜΕΤΑ ΑΠΟ ΧΕΙΡΟΥΡΓΙΚΕΣ ΕΠΕΜΒΑΣΕΙΣ Ή ΣΕ ΑΝΑΠΝΕΥΣΤΙΚΗ ΑΝΕΠΑΡΚΕΙΑ)
- ΠΡΟΒΛΕΨΗ ΕΠΙΤΥΧΟΥΣ ΑΠΟΔΕΣΜΕΥΣΗΣ ΑΠΟ ΤΟ ΜΗΧΑΝΙΚΟ ΑΕΡΙΣΜΟ
- ΕΚΤΙΜΗΣΗ ΑΣΥΝΕΡΓΕΙΑΣ ΑΣΘΕΝΟΥΣ-ΑΝΑΠΝΕΥΣΤΗΡΑ
- ΠΑΡΑΚΟΛΟΥΘΗΣΗ ΑΣΘΕΝΩΝ ΜΕ ΝΕΥΡΟΜΥΙΚΑ ΝΟΣΗΜΑΤΑ
- ΠΑΡΑΚΟΛΟΥΘΗΣΗ ΑΣΘΕΝΩΝ ΜΕ ΧΡΟΝΙΑ ΑΠΟΦΡΑΚΤΙΚΗ ΠΝΕΥΜΟΝΟΠΑΘΕΙΑ

ΕΚΤΙΜΗΣΗ ΛΕΙΤΟΥΡΓΙΚΟΤΗΤΑΣ ΔΙΑΦΡΑΓΜΑΤΟΣ ΣΤΗ ΜΕΘ (ΜΕΤΑ ΑΠΟ ΧΕΙΡΟΥΡΓΙΚΕΣ ΕΠΕΜΒΑΣΕΙΣ Ή ΣΕ ΑΝΑΠΝΕΥΣΤΙΚΗ ΑΝΕΠΑΡΚΕΙΑ)

Intensive Care Med (2017) 43:1441–1452
DOI 10.1007/s00134-017-4928-4

REVIEW

Critical illness-associated diaphragm weakness

Martin Dres[1,2,3*], Ewan C. Goligher[4,5], Leo M. A. Heunks[6] and Laurent J. Brochard[3,5]

Table 2 Prevalence of diaphragm weakness with different definitions and settings

Studies	Settings	Prevalence
Ultrasound studies		
Kim et al. [17]	Weaning	24/82 (29%)
Jiang et al. [20]	Weaning	20/55 (36%)
DiNino et al. [99]	Weaning	15/66 (23%)
Pressure studies		
Demoule et al. [2]	On admission	54/85 (64%)
Watson et al. [9]	Stable ICU patients	26/33 (79%)
Supinski and Callahan [19]	Stable ICU patients	48/57 (84%)
Jung et al. [3]	Weaning	32/40 (80%)
Laghi et al. [1]	Weaning	12/16 (75%)
Dres et al. [5]	Weaning	48/76 (63%)
Lerolle et al. [50]	Post cardiac surgery	19/28 (68%)

ICU Intensive care unit

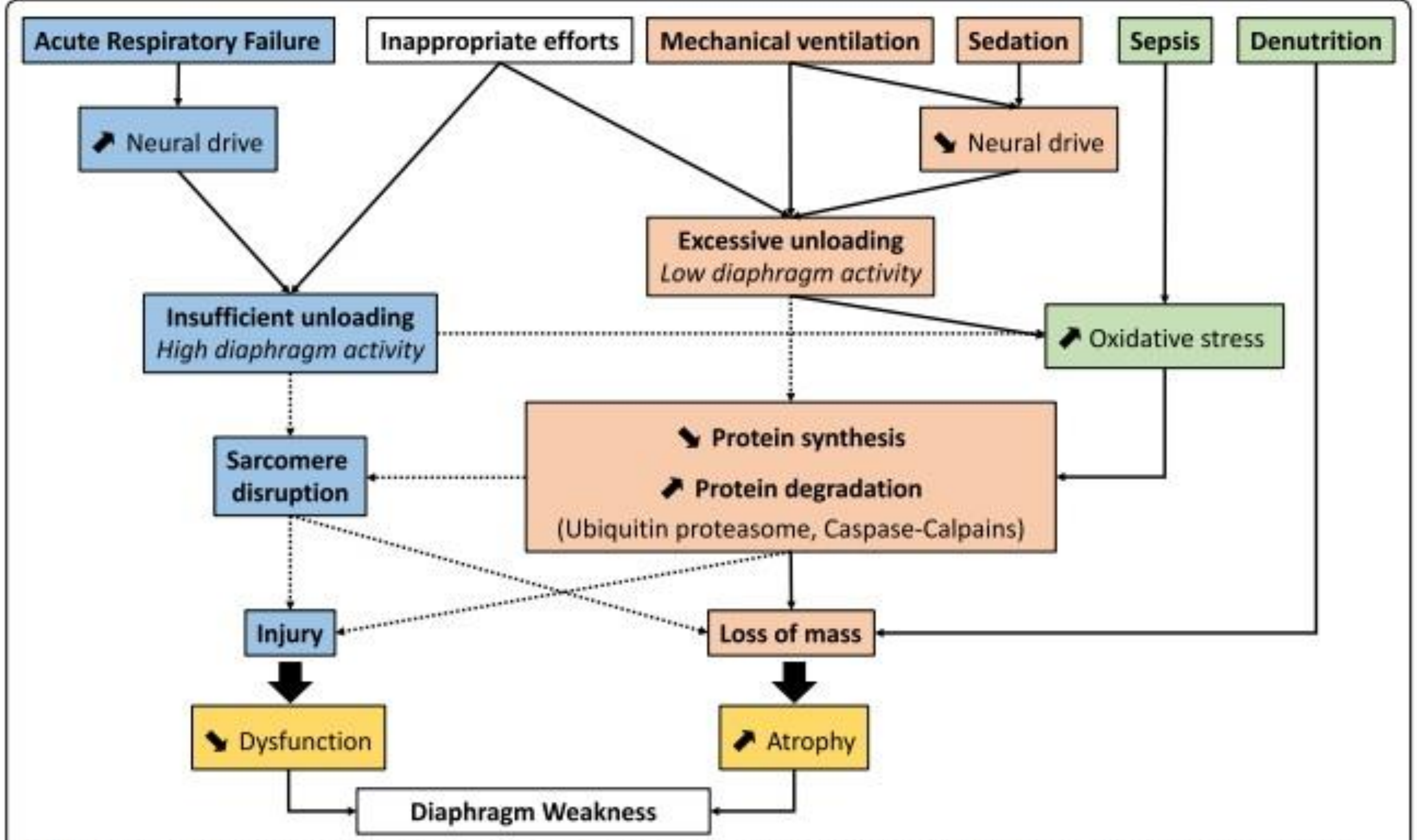

Fig. 3 Schematic illustration of mechanisms pathways involved in the occurrence of diaphragm weakness in critically ill patients. Note that the figure ignores cases of unexcitable muscle in which muscle injury may be reduced or nonexistent. Dashed lines represent uncertain causation and full black lines represent established causation

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REVIEW

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CUT OFF VALUES OF DYSFUNCTION

Table 1 Techniques for assessing diaphragm force and activity in critically ill patients

	Markers of		Cutoff defining diaphragm weakness
	Diaphragm activity	Diaphragm force	
Ultrasound			
TFdi			
Requires a high frequency linear probe	Tidal TFdi	TFdimax	<20% [15]
EXdi			
Requires a low frequency abdominal probe Patient disconnected from ventilator	EXdi	Max EXdi	<1 cm [17]

Table 2 Summary of studies reporting DU to diagnose diaphragmatic dysfunction in the critically ill

Author (year)	Setting	Measures	DU criteria for dysfunction	Comparison	Main findings	Accuracy
Balaji [24] (1990)	Pediatric cardiac ICU	Diaphragm excursion, B-mode	Paralysis: absence of movement or upward movement during inspiration	Fluoroscopy	US allows one to identify diaphragmatic palsy without fluoroscopy	NA
Urvoas [21] (1994)	Pediatric ICU	Diaphragm excursion, M-mode	Paralysis: paradoxical motion. Dysfunction: excursion ≤4 mm	X-rays, fluoroscopy	M-mode allows one to diagnose diaphragmatic paralysis in children	NA
Lerolle [23] (2009)	Cardiac ICU, adult patients	Diaphragm excursion, B-mode	Excursion <25 mm (at maximal inspiratory effort) was considered severe dysfunction	Transdiaphragmatic pressure (Gilbert index)	DU allows one to identify those with and without severe diaphragmatic dysfunction in cardiac patients requiring prolonged mechanical ventilation	AUC 0.93, sensitivity 100 %, specificity 85 %
Sanchez de Toledo [25] (2010)	Pediatric cardiac ICU	Diaphragm excursion, B-mode	Semiquantitative. Diaphragmatic motion was classified as (1) normal; (2) hypokinetic; (3) akinetic; and (4) paradoxical	Fluoroscopy	DU performed by intensivists allows for an early diagnosis of DD in a pediatric cardiac population	Performed by specialist: sensitivity 100 %, specificity 100 %. Performed by a trainee: sensitivity 86 %, specificity 94 %
Mariani [29] (2015)	Medical ICU, adult patients	Diaphragm excursion, B-mode and M-mode	Excursion <10 mm (right) and <11 mm (left)	None	Bilateral DD has a 24 % prevalence among ICU patients ventilated >7 days. No association was found between DD and extubation failure. Agreement higher for M-mode than for 2D images	NA
Valette [28] (2015)	Medical ICU, adult patients	Diaphragm excursion, M-mode	Paralysis: paradoxical or no movement. Dysfunction: excursion <10 mm during unassisted deep	None	Diaphragmatic ultrasonography enhances detection of DD in a medical ICU population	

Intensive Care Med (2017) 43:29–38
DOI 10.1007/s00134-016-4524-z

SYSTEMATIC REVIEW

Assessment of diaphragmatic dysfunction in the critically ill patient with ultrasound: a systematic review

Massimo Zambon[1*], Massimiliano Greco[1], Speranza Bocchino[2], Luca Cabrini[1], Paolo Federico Beccaria[1] and Alberto Zangrillo[2,3]

Table 5 Summary of studies assessing diaphragm atrophy in mechanically ventilated patients

Author (year)	Setting	Patients (*n*)	Main findings
Grosu [16] (2012)	ICU, mechanically ventilated adult patients	7	DU allowed assessment of decrease in Tdi during MV. Diaphragm thickness decreased on average 6 % per day of MV
Cartwright [17] (2013)	Medical ICU, adult patients	16	Diaphragm thickness did not vary significantly
Baldwin [18] (2014)	ICU septic adult patients	16	Survivors of sepsis and a period of mechanical ventilation may have respiratory muscle weakness without remarkable diaphragm wasting
Goligher [27] (2015)	ICU, adult patients	107	Changes in Tdi are common in mechanically ventilated patients and may be associated with DD. Over the first week of MV, thickness decreased in 44 %, did not vary in 44 %, and increased in 10 % of patients. Thickness did not vary in nonventilated patients
Schepens [32] (2015)	ICU, adult patients	54	Diaphragm atrophy occurs quickly after onset of MV and can be accurately monitored with DU. Mean baseline thickness was 1.9 mm, and mean nadir was 1.3 mm, corresponding to a mean change in thickness of 32 %. Length of mechanical ventilation was associated with the degree of atrophy
Zambon [31] (2016)	ICU, adult patients	40	There is a linear relationship between ventilator support and diaphragmatic atrophy rate. Daily atrophy rate ranged from −7.5 % under CMV to +2.3 % during SB

Tdi thickness of diaphragm, *TF* thickening fraction, *MV* mechanical ventilation, *CMV* controlled mechanical ventilation, *SB* spontaneous breathing, *DU* diaphragmatic ultrasound, *DD* diaphragmatic dysfunction, *ICU* intensive care unit

Intensive Care Med (2017) 43:29–38
DOI 10.1007/s00134-016-4524-z

SYSTEMATIC REVIEW

Assessment of diaphragmatic dysfunction in the critically ill patient with ultrasound: a systematic review

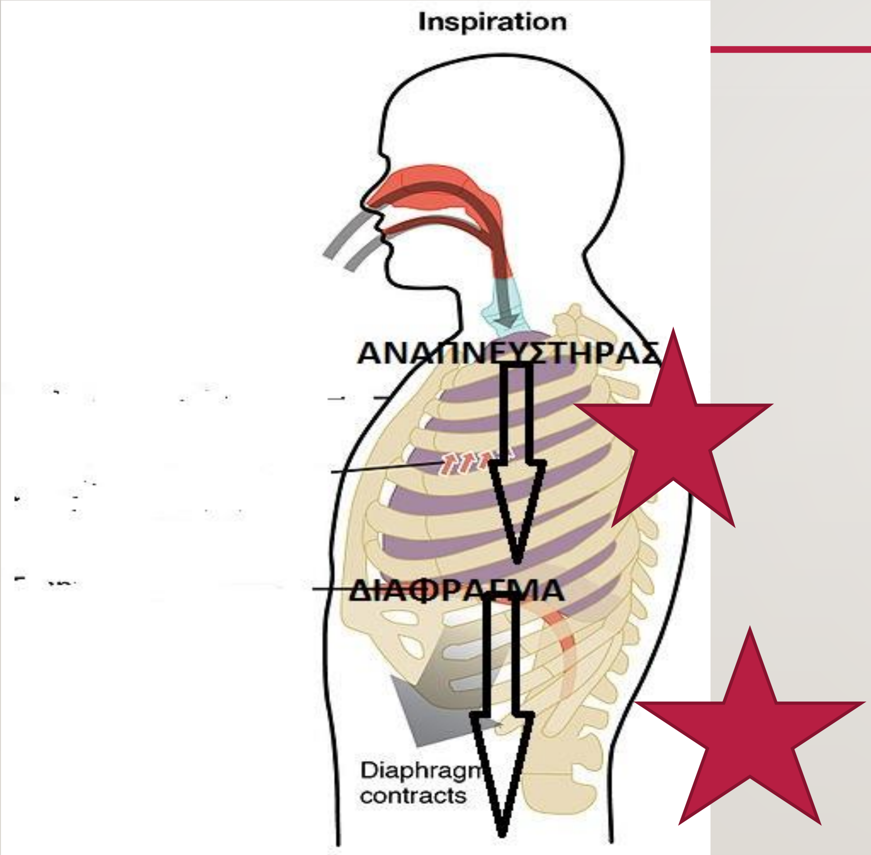
Massimo Zambon[1*], Massimiliano Greco[2], Speranza Bocchino[2], Luca Cabrini[2], Paolo Federico Beccaria[2] and Alberto Zangrillo[2,3]

Table 4 Summary of studies evaluating the accuracy of DU to assess the diaphragm muscular workload

Author (year)	Setting	Measures	Comparison	Accuracy
Lerolle [23] (2009)	Cardiac ICU, adult patients	Diaphragm excursion at maximal inspiratory effort (through pleural effusions)	Transdiaphragmatic pressure (Gilbert index)	Maximal excursion significantly correlated with Gilbert index ($\rho = 0.64$)
Vivier [19] (2012)	ICU, adult patients under NIV post-extubation	TF	Diaphragmatic pressure–time product (PTPdi)	TF significantly correlated with PTPdi ($\rho = 0.74$)
Goligher [26] (2015)	ICU, adult patients	TF	Diaphragm electrical activity and transdiaphragmatic pressure	TF significantly correlated with diaphragm electrical activity and transdiaphragmatic pressure ($r^2 = 0.32$ and 0.28)
Umbrello [30] (2015)	Surgical ICU, adult patients	TF and diaphragmatic excursion	Diaphragm and esophageal time–pressure product (PTPdi and PTPes)	TF significantly correlated with PTPdi and PTPes ($r = 0.701$ and 0.801). No significant correlation for diaphragmatic excursion

Tdi thickness of diaphragm, *TF* thickening fraction, *MV* mechanical ventilation, *DU* diaphragmatic ultrasound, *DD* diaphragmatic dysfunction, *ICU* intensive care unit

ΑΣΘΕΝΕΙΣ ΣΕ ΜΗΧΑΝΙΚΗ ΥΠΟΣΤΗΡΙΞΗ ΤΗΣ ΑΝΑΠΝΟΗΣ



- In fact, diaphragm excursion during an assisted breath represents the sum of two forces acting in the same direction:
- the force of the diaphragm contraction by itself,
- and the passive displacement of the diaphragm by the pressure provided by the ventilator.
- With increasing levels of PressureSupport,
- **<u>the diaphragm is unloaded</u>** and an increasing part of the work of breathing is performed by the ventilator.


Umbrello *et al. Critical Care* (2015) 19:161
DOI 10.1186/s13054-015-0894-9

CRITICAL CARE

RESEARCH Open Access

Diaphragm ultrasound as indicator of respiratory effort in critically ill patients undergoing assisted mechanical ventilation: a pilot clinical study

Michele Umbrello[1,2*], Paolo Formenti[1], Daniela Longhi[2], Andrea Galimberti[2], Ilaria Piva[2], Angelo Pezzi[1], Giovanni Mistraletti[1,2], John J Marini[3] and Gaetano Iapichino[1,2]

Umbrello et al. Critical Care (2015) 19:161
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CRITICAL CARE

RESEARCH Open Access

Diaphragm ultrasound as indicator of respiratory effort in critically ill patients undergoing assisted mechanical ventilation: a pilot clinical study

Michele Umbrello[1,2*], Paolo Formenti[1], Daniela Longhi[2], Andrea Galimberti[2], Ilaria Piva[2], Angelo Pezzi[1], Giovanni Mistraletti[1,2], John J Marini[3] and Gaetano Iapichino[1,2]

- In this physiologic, clinical pilot study we found that diaphragm excursion was not correlated to any index of muscle effort under varying levels of muscle loading; we also found that diaphragm thickening was a good indicator of changes of inspiratory muscle effort in response to modifications of the support level.
- Monitoring of diaphragm contractile activity during the weaning phase should be performed with diaphragm thickening, and the suggested cutoffs for diaphragm dysfunction, as far as diaphragmatic excursion is concerned, should not be considered valid during assisted mechanical ventilation.

ΠΡΟΒΛΕΨΗ ΕΠΙΤΥΧΟΥΣ ΑΠΟΔΕΣΜΕΥΣΗΣ ΑΠΟ ΤΟ ΜΗΧΑΝΙΚΟ ΑΕΡΙΣΜΟ

Table 3 Summary of studies assessing the performance of DU in predicting weaning outcome

Author (year)	Setting	Measures	Comparison	Main findings	Best cutoff to identify DD	Accuracy
Jiang [22] (2004)	Medical ICU, adult patients	Diaphragm excursion (liver/spleen displacement)	Traditional weaning indexes (included RSBI)	DU (mean liver/spleen displacement) can predict successful extubation	11 mm	Sensitivity 84.4 %, specificity 82.6 %
Kim [20] (2011)	Medical ICU, adult patients	Diaphragmatic excursion, M-mode	RSBI	Diaphragmatic dysfunction assessed with DU can predict weaning failure	14 mm (right) and 12 mm (left)	Sensitivity 60 %, specificity 76 %, AUC 0.68
Dinino [15] (2014)	ICU, adult patients	Tdi and TF	RSBI	TF predicts extubation success or failure during spontaneous breathing or pressure support (Δ5/5) trials	30 %	Sensitivity 88 %, specificity 71 %, AUC 0.79
Ferrari [33] (2014)	Adult high dependency unit	TF	RSBI	TF can predict successful extubation	36 %	Sensitivity 0.82, specificity 0.88

Tdi thickness of diaphragm, *TF* thickening fraction, *MV* mechanical ventilation, *DU* diaphragmatic ultrasound, *DD* diaphragmatic dysfunction, *ICU* intensive care unit, *RSBI* rapid shallow breathing index

Intensive Care Med (2017) 43:29–38
DOI 10.1007/s00134-016-4524-z

SYSTEMATIC REVIEW

Assessment of diaphragmatic dysfunction in the critically ill patient with ultrasound: a systematic review

Massimo Zambon[1*], Massimiliano Greco[2], Speranza Bocchino[2], Luca Cabrini[2], Paolo Federico Beccaria[2] and Alberto Zangrillo[2,3]

All four studies concluded that their respective measurements can predict successful extubation or weaning failure,

with cut-of values of 11–14 mm in excursion

and 30–36% in thickening fraction

being most sensitive and specific.

Intensive Care Med (2017) 43:29–38
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SYSTEMATIC REVIEW

CrossMark

Assessment of diaphragmatic dysfunction in the critically ill patient with ultrasound: a systematic review

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Intensive Care Med (2016) 42:1107–1117
DOI 10.1007/s00134-016-4245-3

REVIEW

Ultrasonography evaluation during the weaning process: the heart, the diaphragm, the pleura and the lung

P. Mayo[1*], G. Volpicelli[2], N. Lerolle[3], A. Schreiber[4], P. Doelken[5] and A. Vieillard-Baron[6,7,8]

Table 2 Indices of diaphragmatic function of potential utility for weaning from mechanical ventilatory support

Measurement	Value	Potential utility
Diaphragmatic excursion during SBT	<11 mm	Increased likelihood of failure of SBT
Best diaphragmatic excursion on right or left	>25 mm	Increased likelihood of success of SBT
Thickening fraction of diaphragm during SBT	>30–36 %	Increased likelihood of success of SBT
Right- and left-sided diaphragmatic excursion	Bilateral absence of diaphragmatic excursion	Increased likelihood of failure of SBT

SBT spontaneous breathing trial

ΕΚΤΙΜΗΣΗ ΑΣΥΝΕΡΓΕΙΑΣ ΑΣΘΕΝΟΥΣ-ΑΝΑΠΝΕΥΣΤΗΡΑ

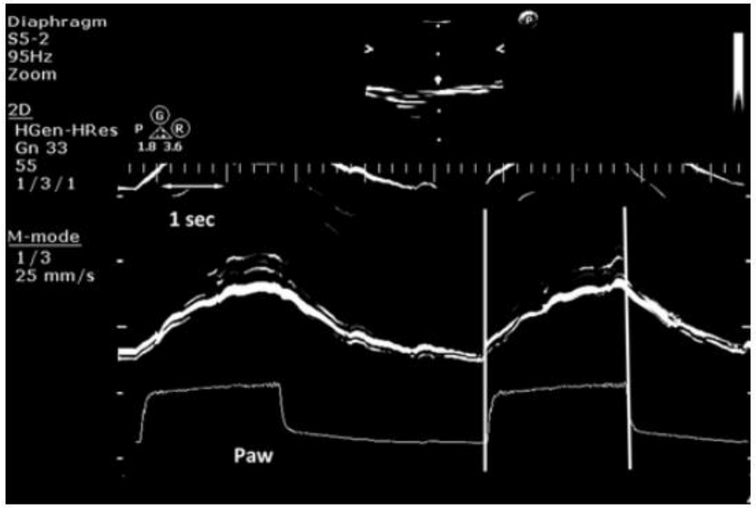

Fig. 4 Simultaneous recordings of diaphragmatic contraction in M-mode sonography and airway pressure waveform (Paw), in a patient under pressure support ventilation. Patient–ventilator synchrony is confirmed by the perfect synchronization of the beginning (*first vertical line*) and the end of the diaphragmatic contraction (*second vertical line*) and the triggering and the cycling off of the

Intensive Care Med (2013) 39:801–810
DOI 10.1007/s00134-013-2823-1

REVIEW

Dimitrios Matamis
Eleni Soilemezi
Matthew Tsagourias
Evangelia Akoumianaki
Saoussen Dimassi
Filippo Boroli
Jean-Christophe M. Richard
Laurent Brochard

Sonographic evaluation of the diaphragm in critically ill patients. Technique and clinical applications

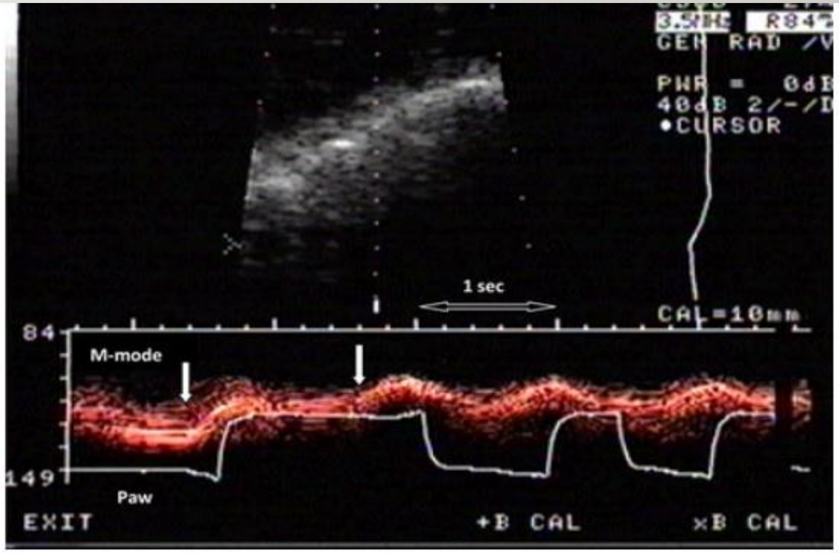

Fig. 5 Diaphragmatic contraction in M-mode sonography and Paw in a COPD patient under pressure support ventilation, indicating patient–ventilator asynchrony. In the first assisted breath, ventilator inspiratory time is much longer compared to the second breath. In the first assisted breath, we notice two diaphragmatic contractions (*arrows*); the second diaphragmatic contraction prolongs the inspiratory time of the assisted breath

ΑΣΥΝΕΡΓΕΙΑ

ΑΡΙΣΤΗ ΣΥΝΕΡΓΑΣΙΑ

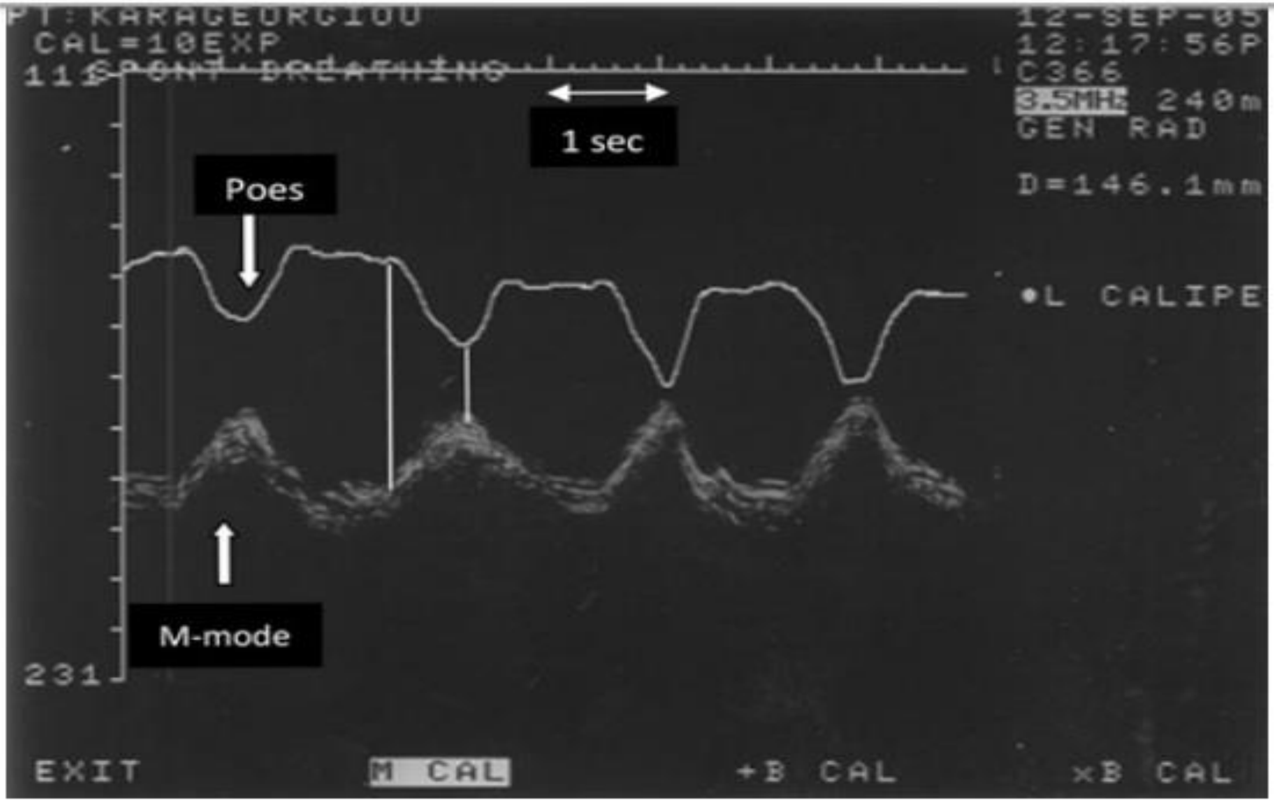

Fig. 8 Simultaneous recording of the esophageal pressure and M-mode diaphragmatic sonography. Notice the perfect synchronization of the beginning of diaphragmatic contraction and the drop of the esophageal pressure (*first vertical line*). The *second vertical line* indicates the end of inspiration and the maximal pressure drop in the esophageal pressure

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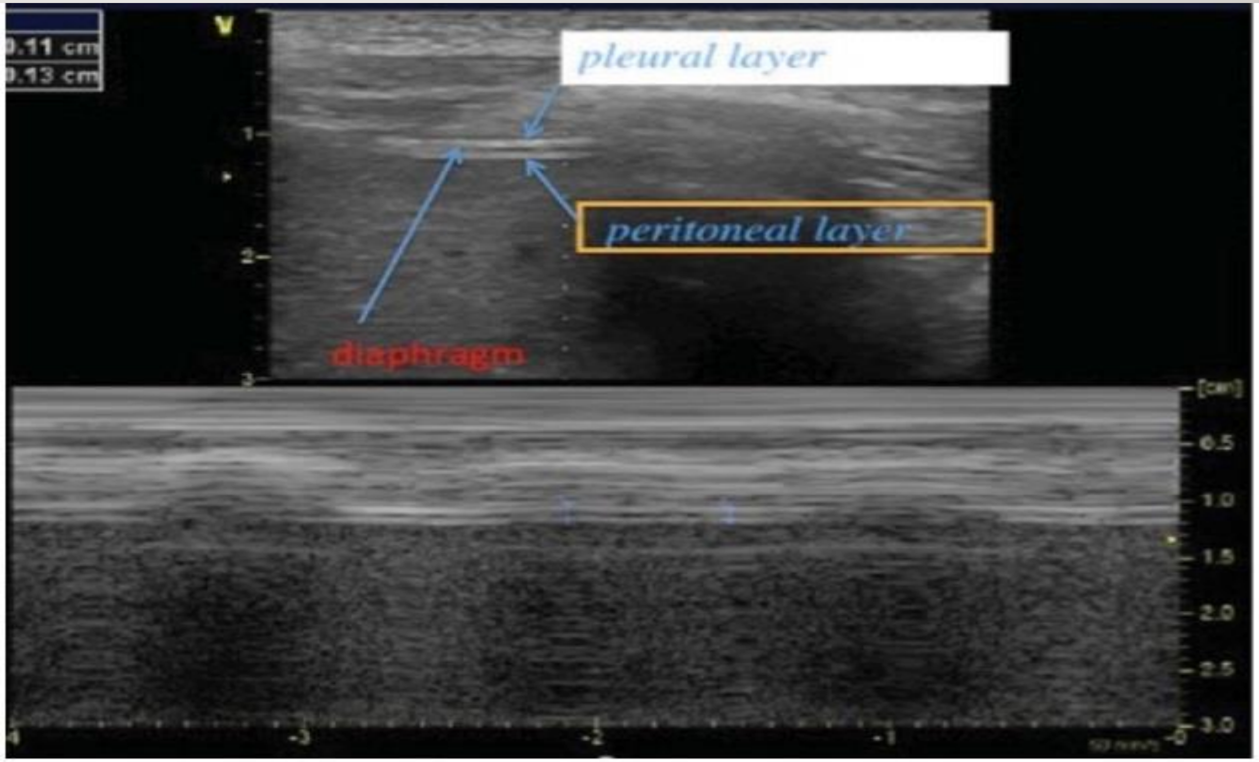
DOI 10.3233/JND-170276
IOS Press

Review

Diaphragm: Pathophysiology and Ultrasound Imaging in Neuromuscular Disorders

Abdallah Fayssoil[a,b,*], Anthony Behin[b], Adam Ogna[c], Dominique Mompoint[a], Helge Amthor[a,d], Bernard Clair[a], Pascal Laforet[b,d], Arnaud Mansart[a], Helene Prigent[a,d], David Orlikowski[a], Tanya Stojkovic[b], Stéphane Vinit[d], Robert Carlier[a,d], Bruno Eymard[b], Frederic Lofaso[a,d] and Djillali Annane[a]



trasound imaging from the zone of apposition for the measurement of diaphragm thickness. The diaphragm is located tal muscles and we can distinguish three layers: a hypo-echogenic thick layer (diaphragm muscle) surrounded by two es (pleural layer and peritoneal layer). Here is a reduced diaphragm thickness (1.3 mm) in a patient with Duchenne

ΠΑΡΑΚΟΛΟΥΘΗΣΗ ΑΣΘΕΝΩΝ ΜΕ ΧΡΟΝΙΑ ΑΠΟΦΡΑΚΤΙΚΗ ΠΝΕΥΜΟΝΟΠΑΘΕΙΑ

Original Article

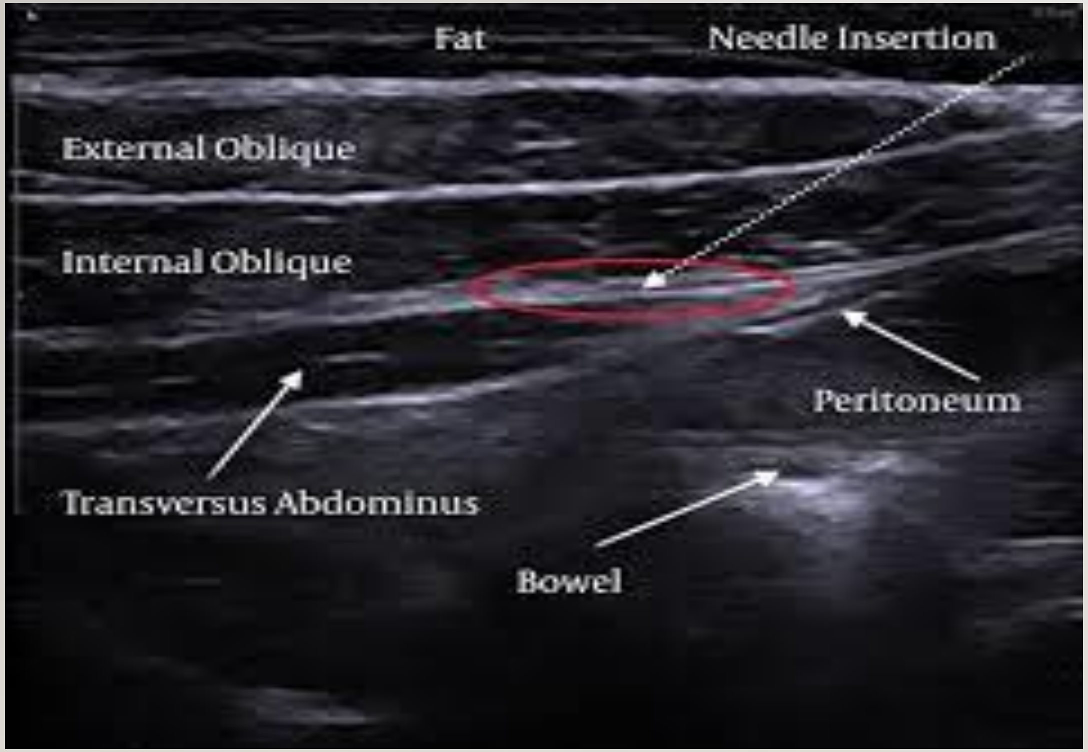
Study of the diaphragm in chronic obstructive pulmonary disease using ultrasonography

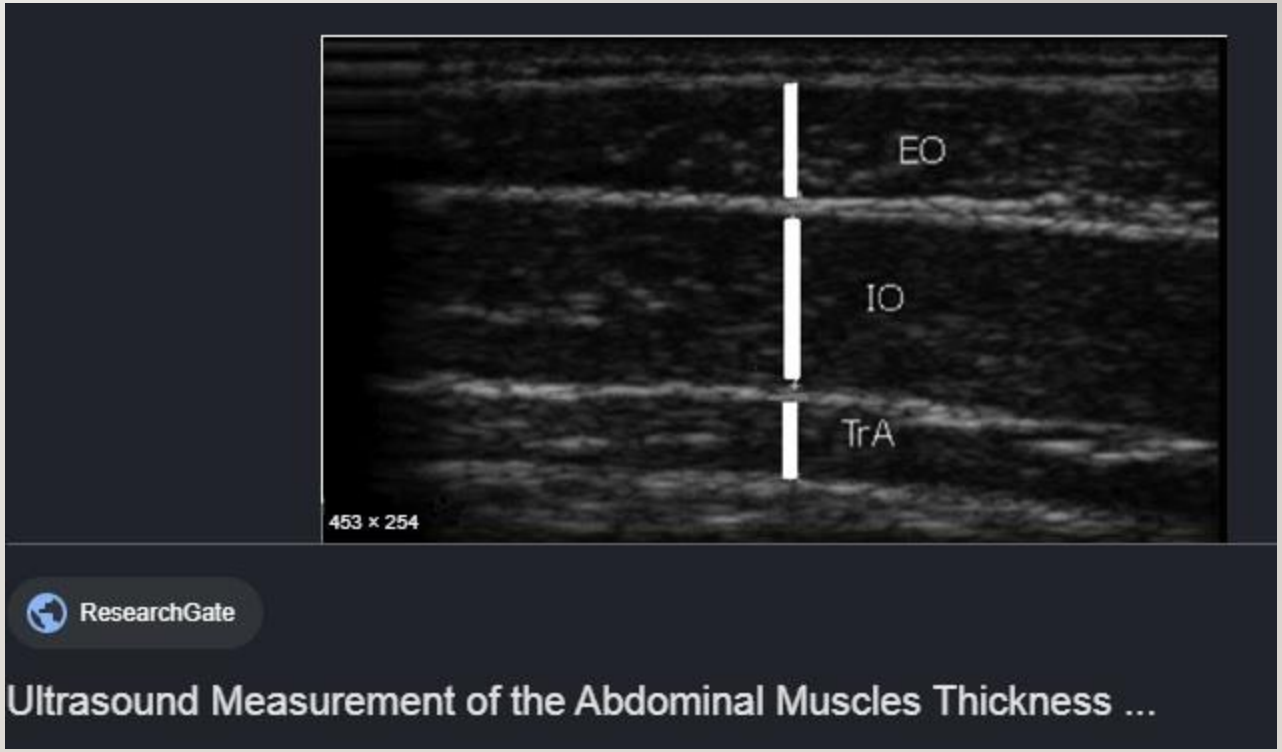
Sanket Jain, Girija Nair, Abhishek Nuchin, Abhay Uppe

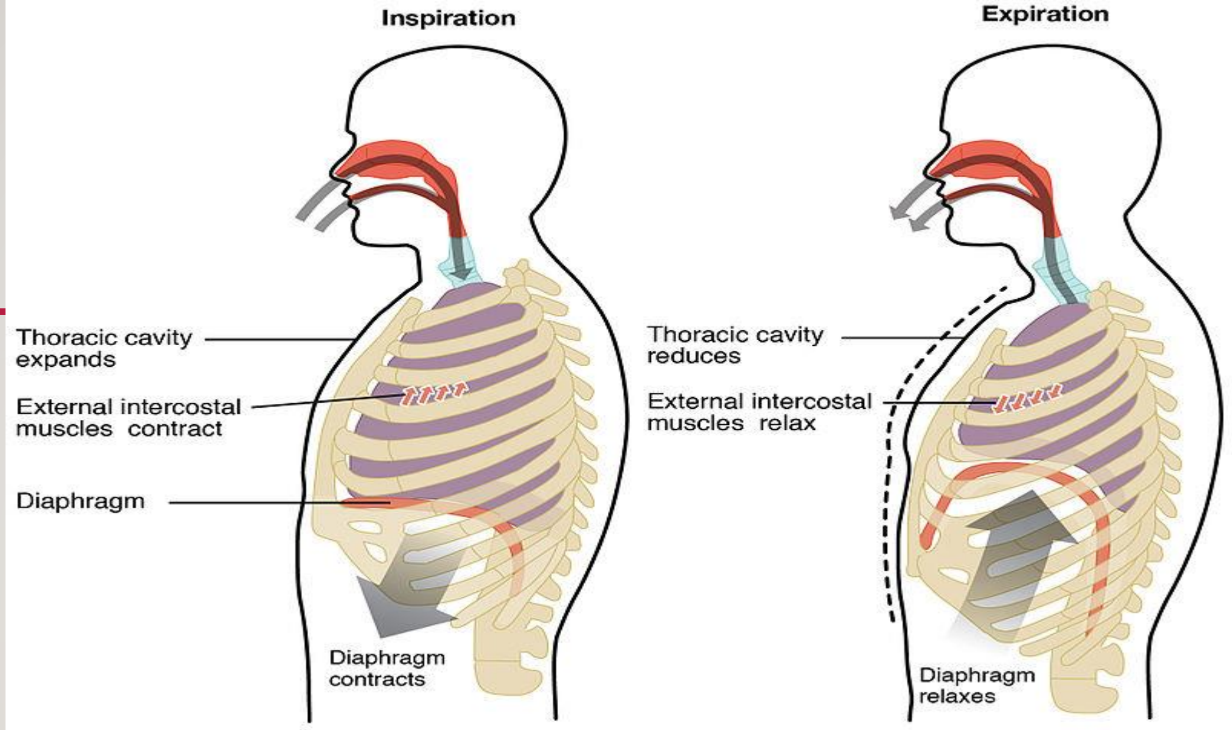
Department of Pulmonary Medicine, Dr. DY Patil Medical College, Navi Mumbai, Maharashtra, India

Results: The movement of diaphragm was reduced in mild to moderate COPD (A and B) but increased in COPD with Grade C. Movement of diaphragm was significantly more in cases with COPD Grade B (2.329 cm) and C (2.269 cm) as compared to controls (1.891 cm). Mean diaphragmatic thickness during inspiration and expiration, change in thickness, and zone of apposition were significantly higher in patients with COPD score Grade C as compared to Grade A or B. Zone of apposition was significantly decreased in Grade A (3.257 cm) and B (3.429 cm) compared to control (4.268 cm), while it was significantly increased in cases with Grade C (5.138 cm). **Conclusion:** The diaphragm is the main muscle of respiration, and study of diaphragm is very important in COPD. The diaphragm thickness, movement, and zone of apposition were significantly reduced in mild to moderate COPD but increased in severe COPD. This cannot be explained by physiotherapy or collagen accumulation. Hence, diaphragm muscle biopsy and electromyogram study in COPD patients will be required to get a better understanding of this muscle in COPD.

ΕΚΠΝΕΥΣΤΙΚΟΙ ΜΥΕΣ







ΣΑΣ ΕΥΧΑΡΙΣΤΩ ΠΟΛΥ