

# Ultrasound for Respiratory Mechanics Monitoring and Weaning



Jen-Tang, Sun MD

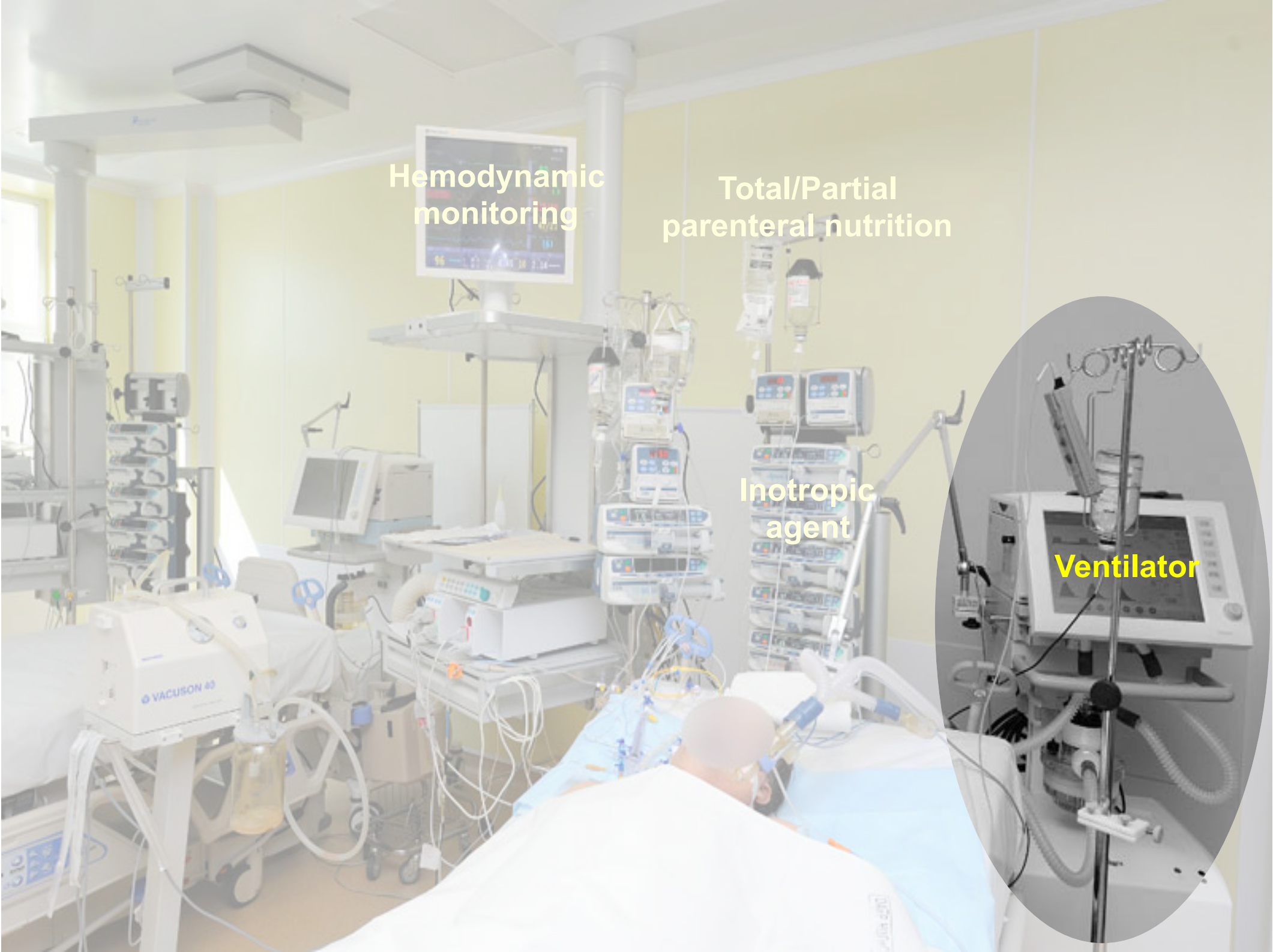
Department of emergency medicine,  
Far East Memorial Hospital

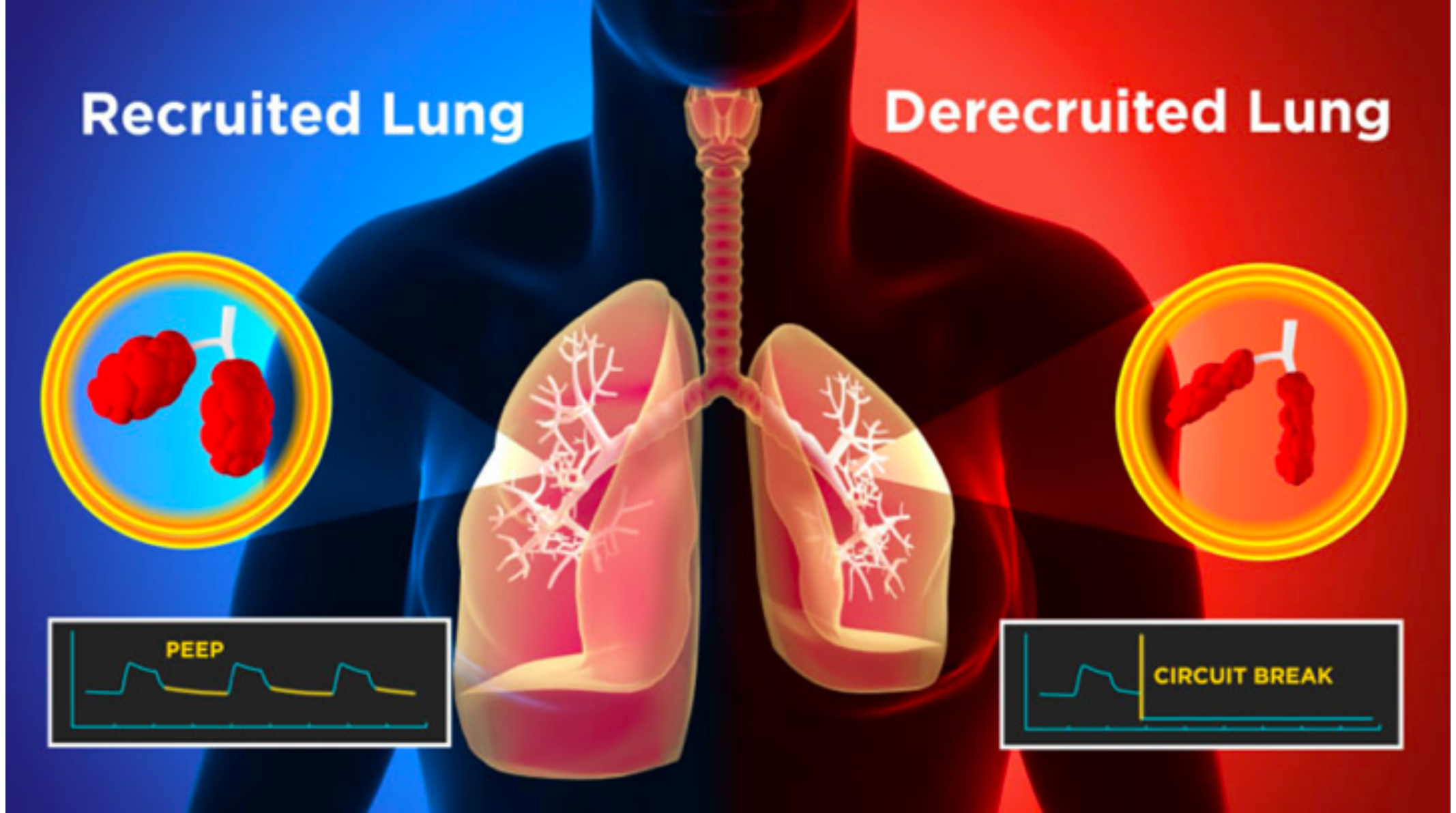
Hemodynamic monitoring

Total/Partial parenteral nutrition

Inotropic agent

Ventilator





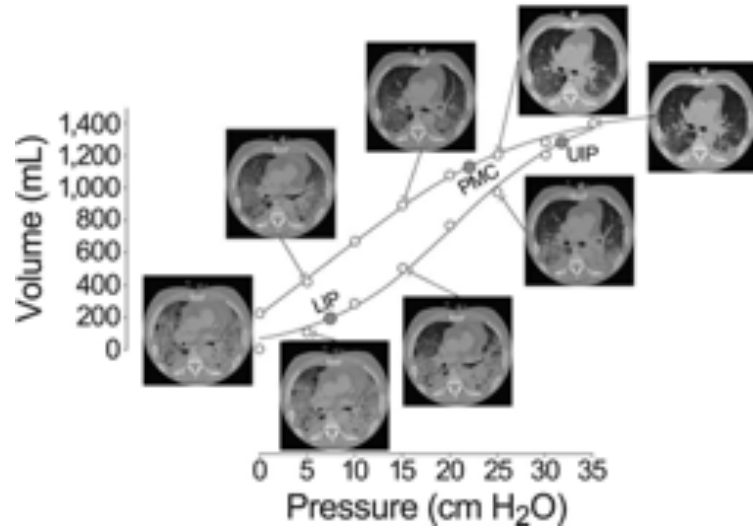
- Sustain inflation
- Sighs

- Prone position
- High PEEP, low tidal volume

- VV ECMO

# Evaluation of lung recruitment

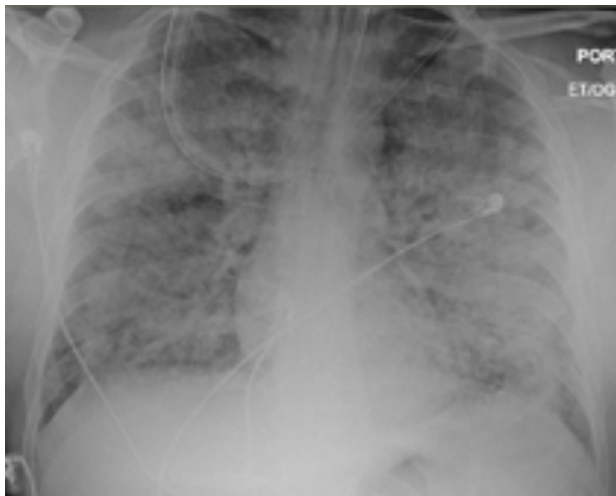
- P-V curve



- Chest CT

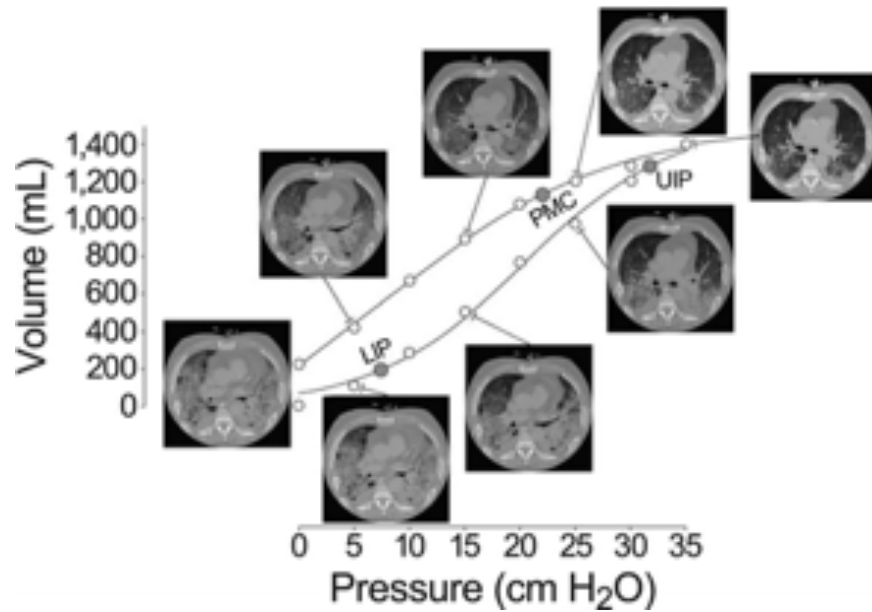


- X ray



- Clinical





## P-V curve

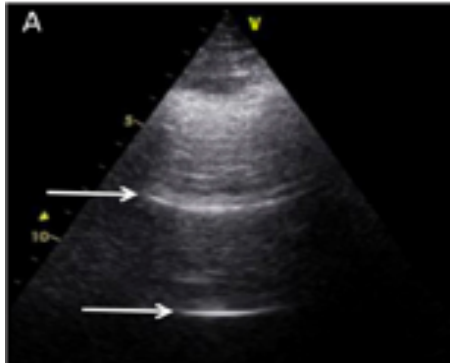
- Deep sedation & musc relaxation
- Can't perform in spontaneously breathing pt
- Special software



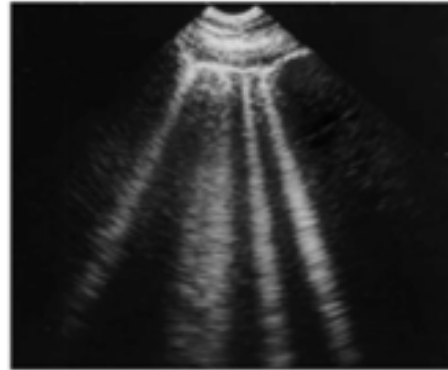
## Chest CT

- Radiation exposure
- Transport pt outside the ICU
- Time-consuming

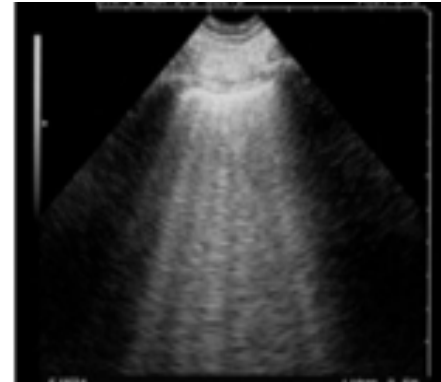
# Lung aeration pattern



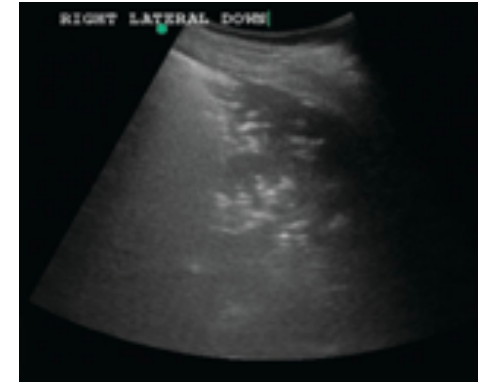
Normal



Moderate loss of aeration



Severe loss of aeration



Consolidation

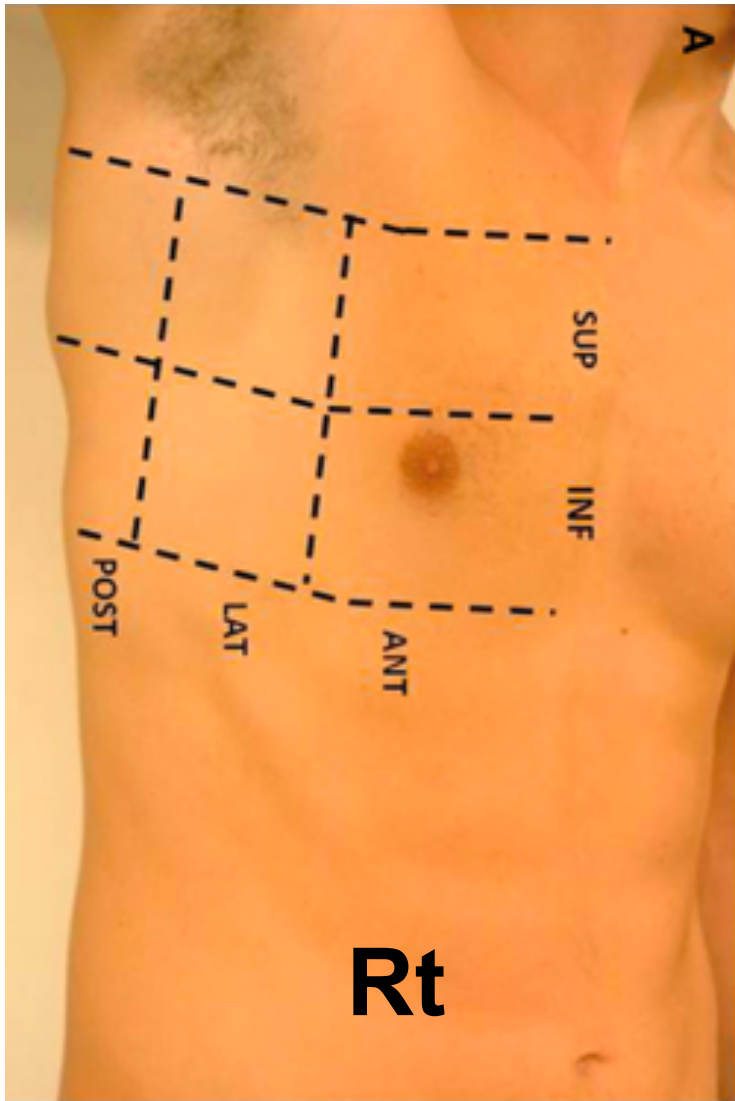


- A line
- B line < 2

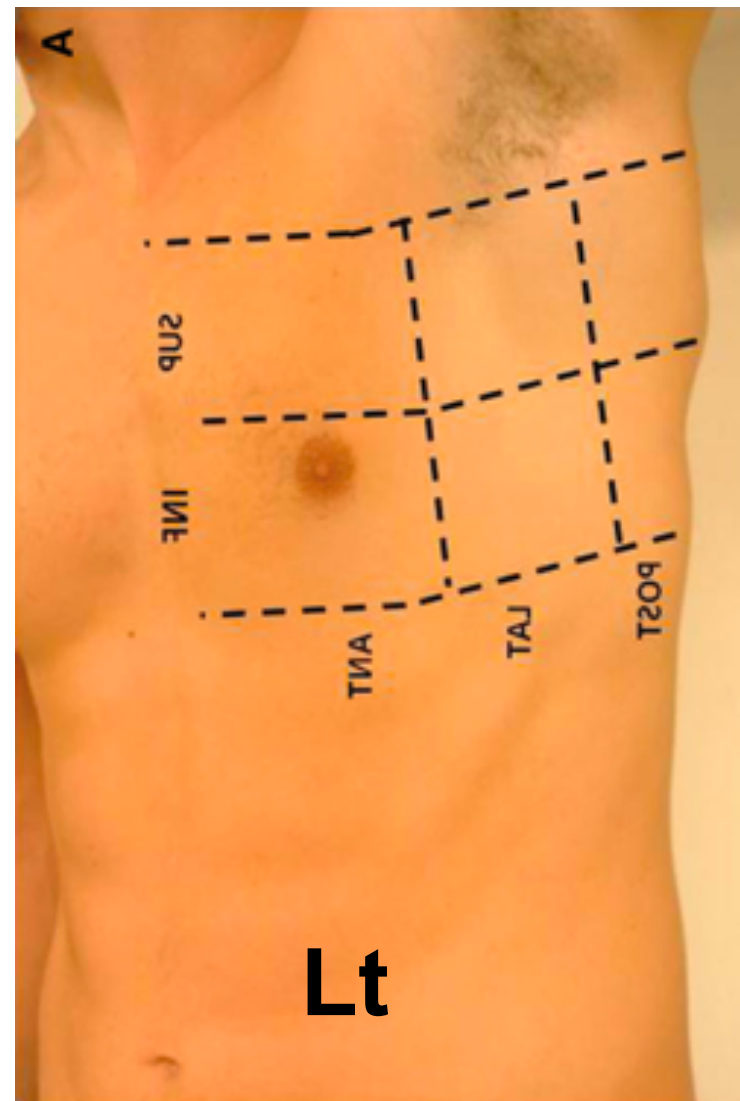
- Multiple well defined B lines

- Multiple coalescent B lines

- Dynamic airbronchogram

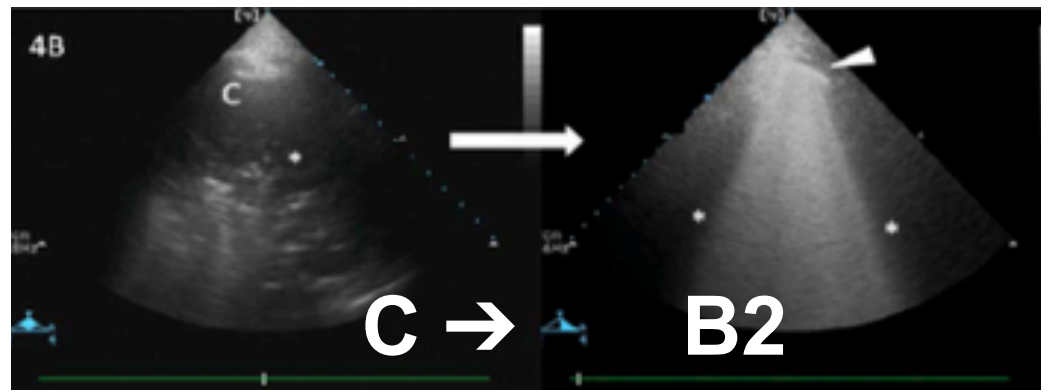
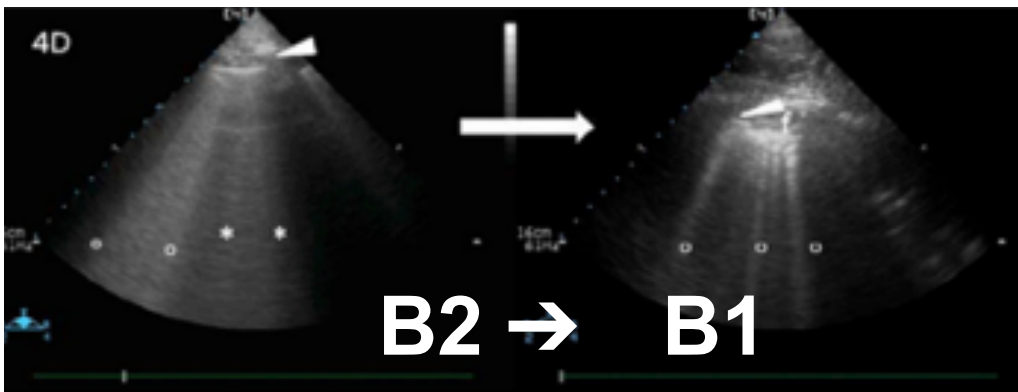
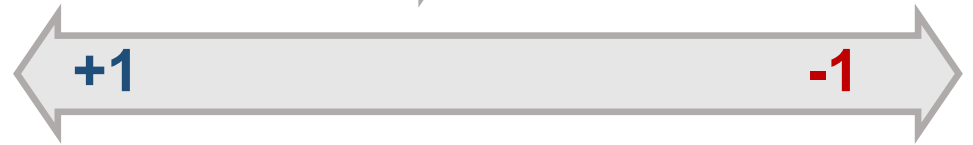
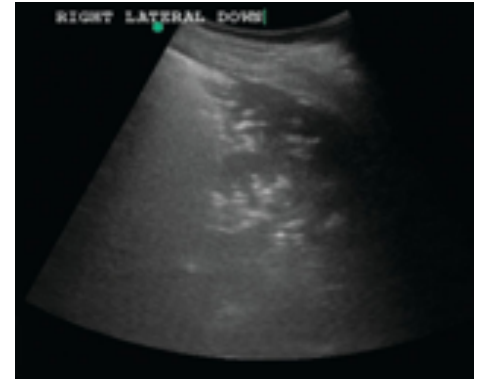
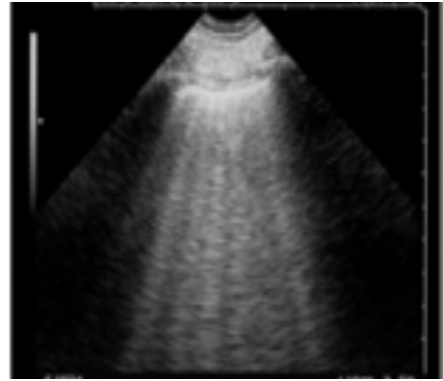
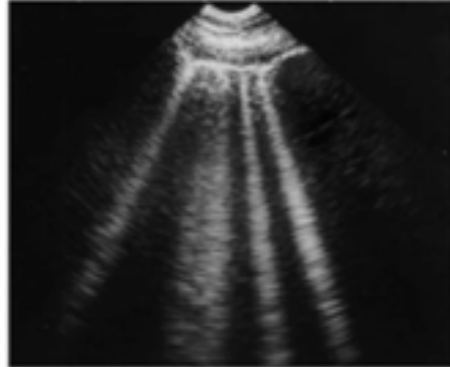
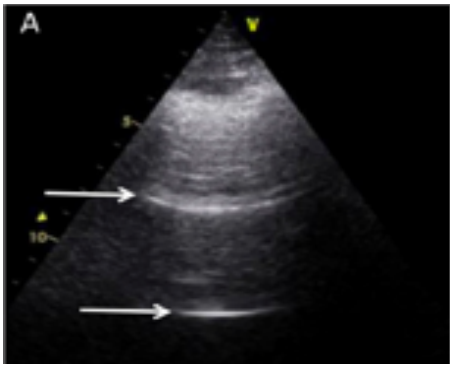


**Rt**

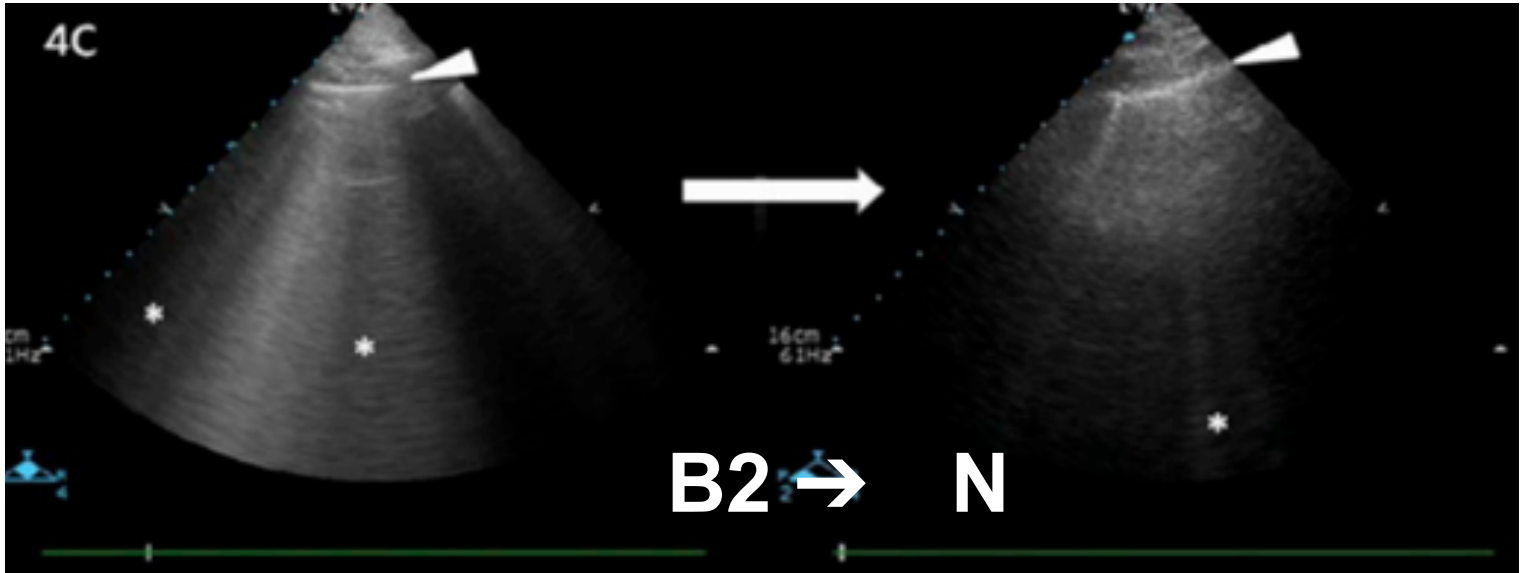
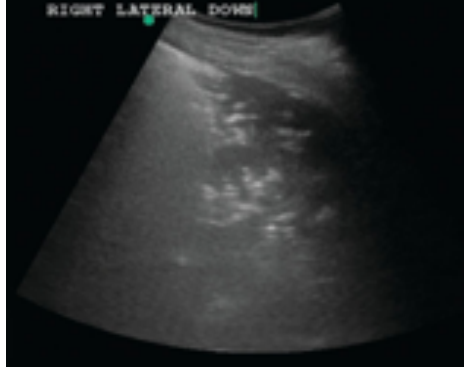
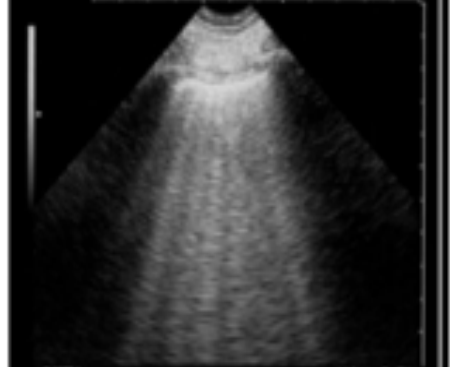
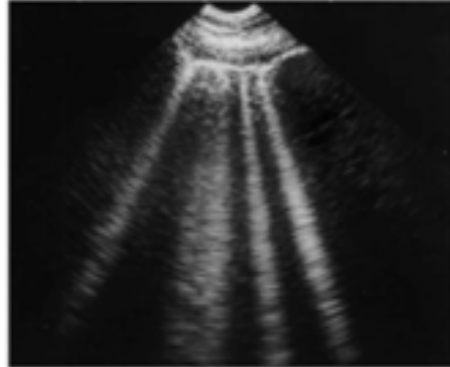
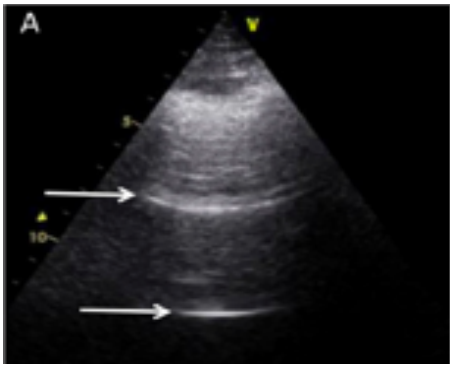


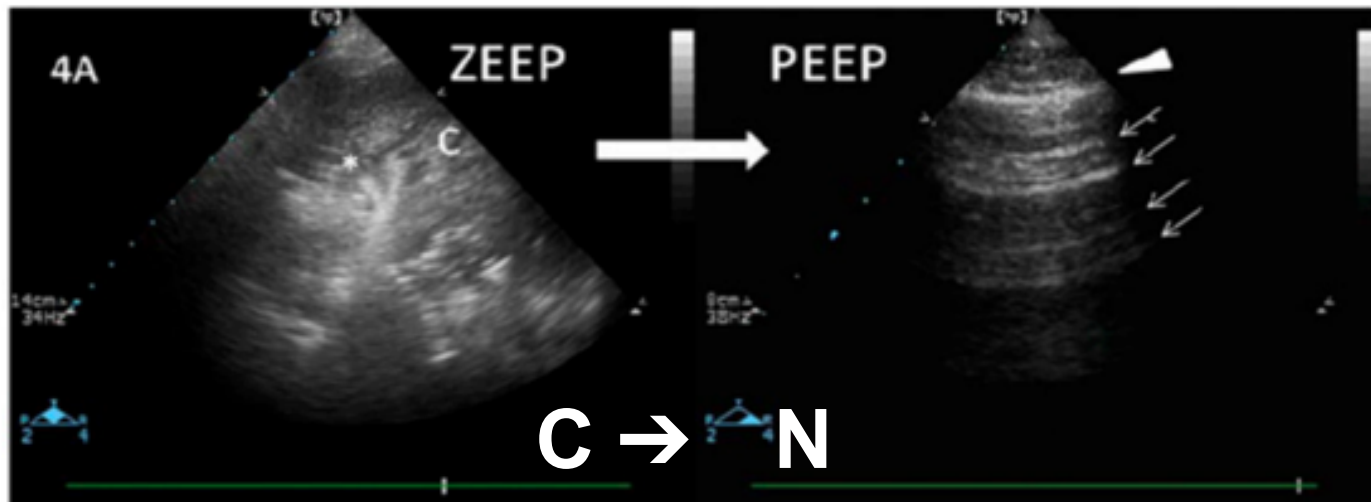
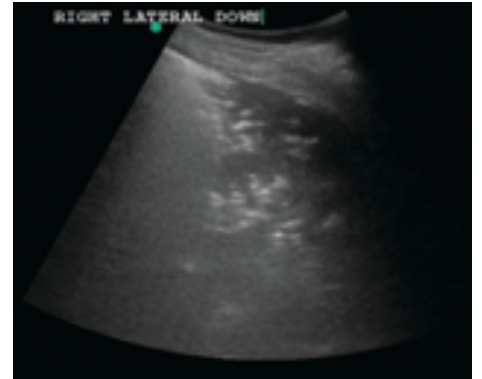
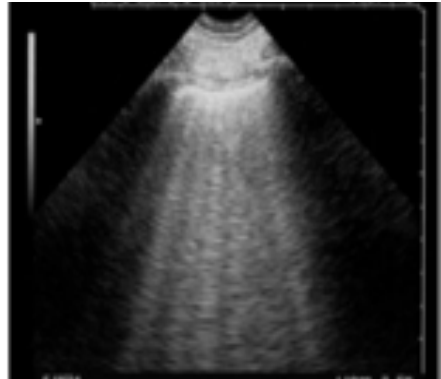
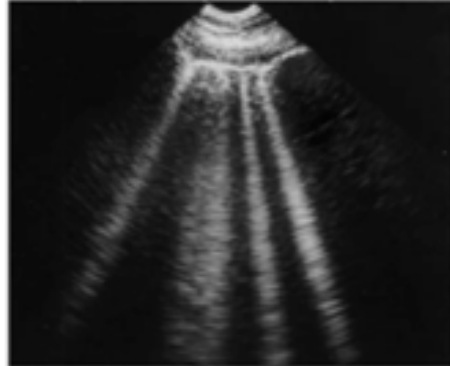
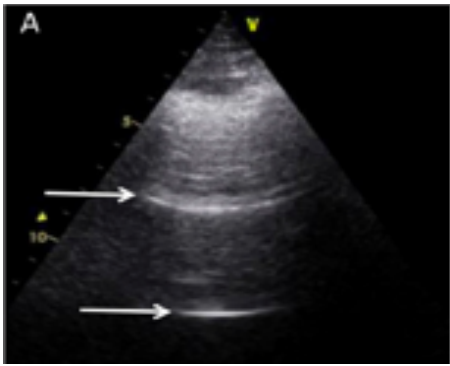
**Lt**

Total 12 regions need to be evaluated!



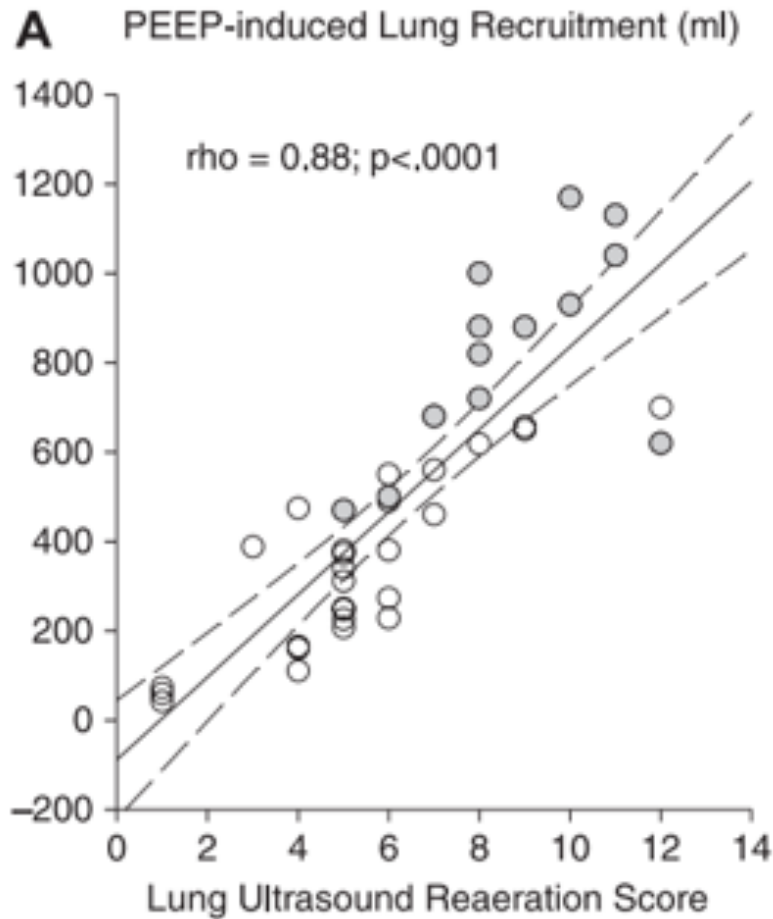
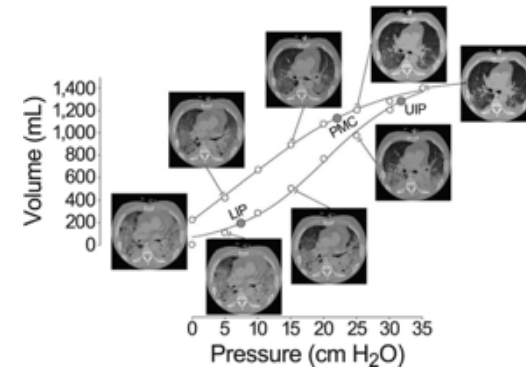








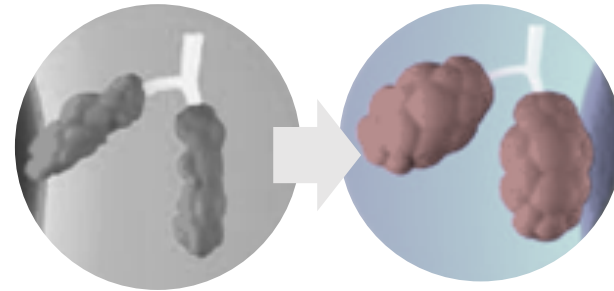
VS



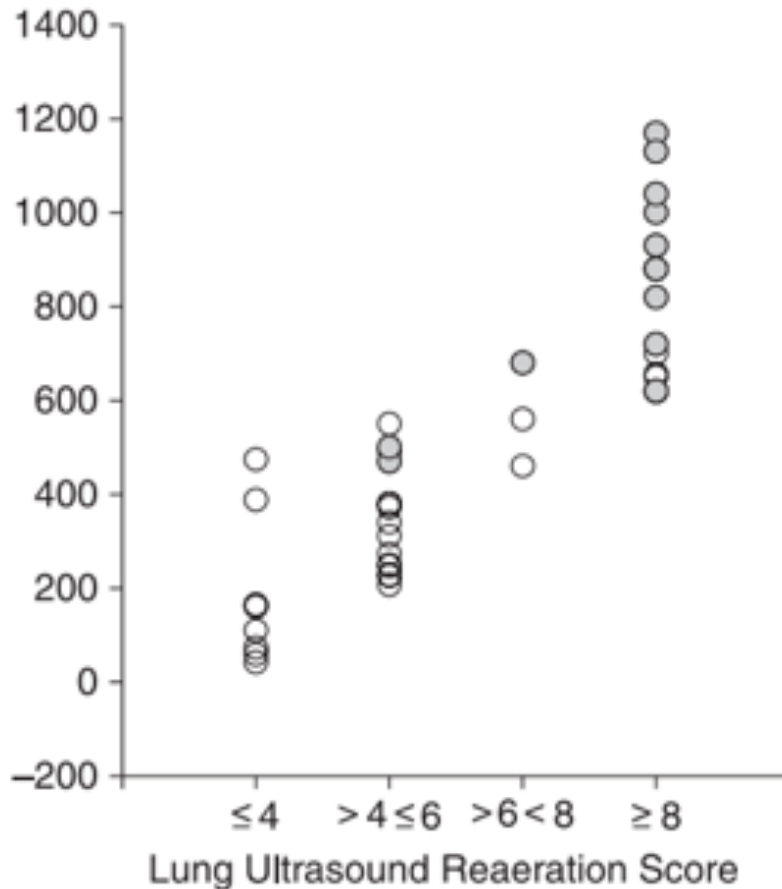
Highly significant correlation between PV curves and US reaeration score ( $Rho=0.88; P<0.0001$ )



and



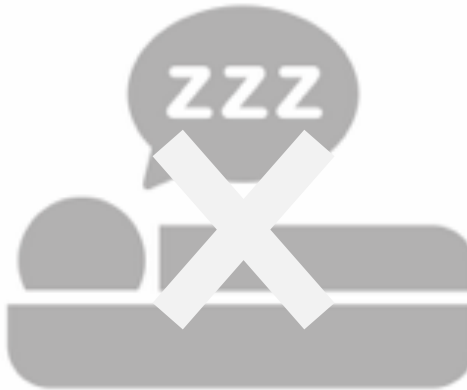
**B** PEEP-induced Lung Recruitment (ml)



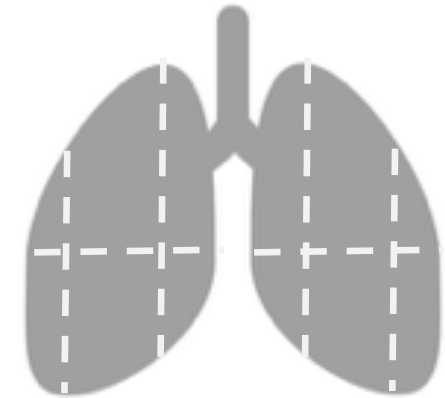
+ 8 or more = +600ml  
+ 4 or less = +75~450 ml  
( $Rho=0.63$ ;  $P<0.05$ )



Repeatable



No need deep sedation  
and paralysis



Regional analysis

After general condition improving,  
what is the next step?



**Weaning!**



## Supportive not therapeutic !!!

- 👎 Ventilator related trauma
- 👎 Oxygen toxicity
- 👎 Ventilator induced diaphragm dysfunction



## Weaning Parameters

- Minute ventilation ( $V_e$ )
- Max inspiratory pressure ( $PI_{max}$ )
- Breathing frequency
- Rapid shallow breathing index (RSBI, RR/tidal volume)
- Tracheal airway occlusion pressure 0.1 s ( $P_{0.1}$ )



40%

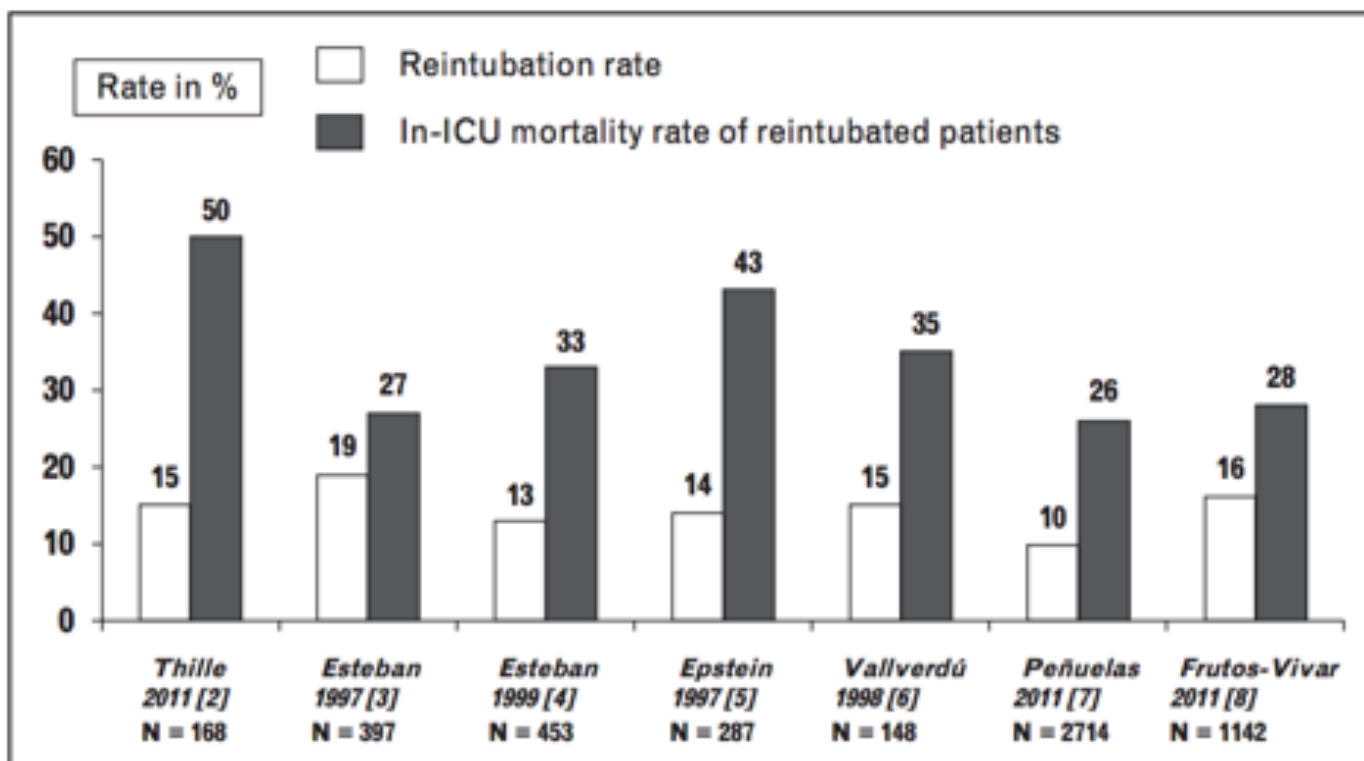
Ventilator  
dependent in ICU

20%

Difficult  
weaning

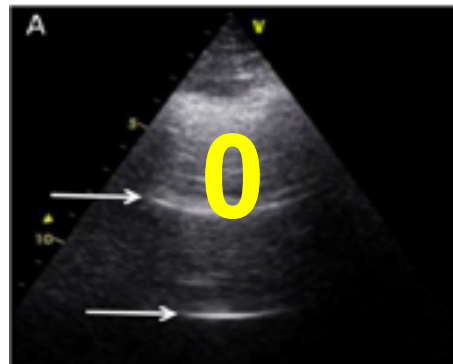
40%

ICU stay spend  
for weaning

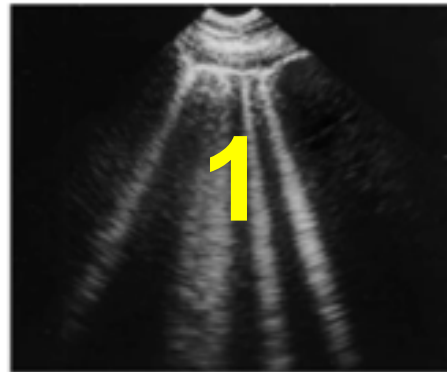


Thille AW. Curr Opin Crit Care. 2013;19(1):57-64

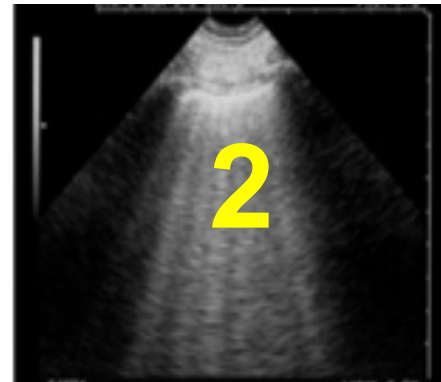
# Before and end of SBT



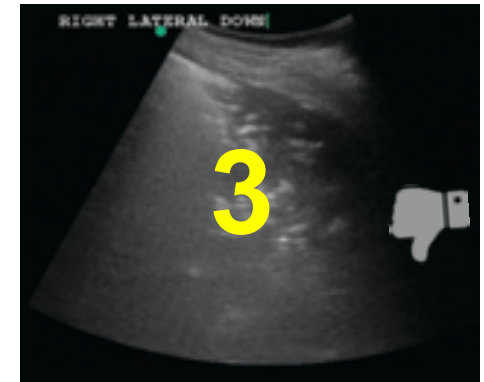
Normal



Moderate loss of aeration



Severe loss of aeration

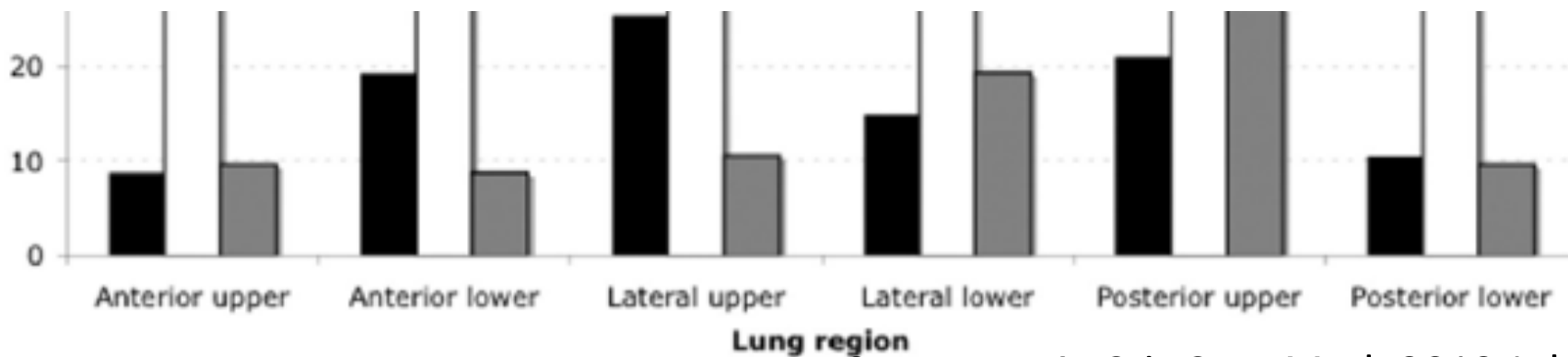
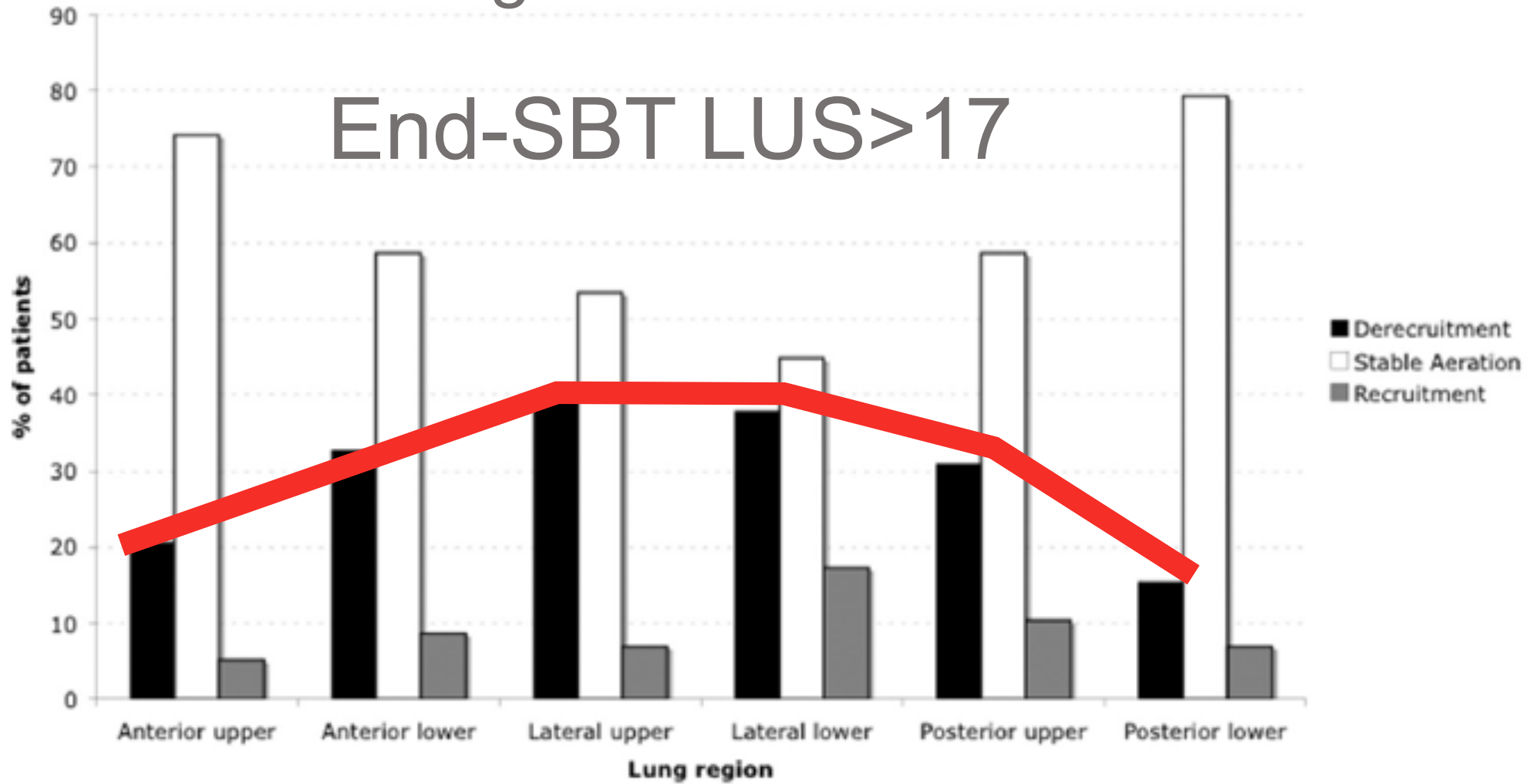


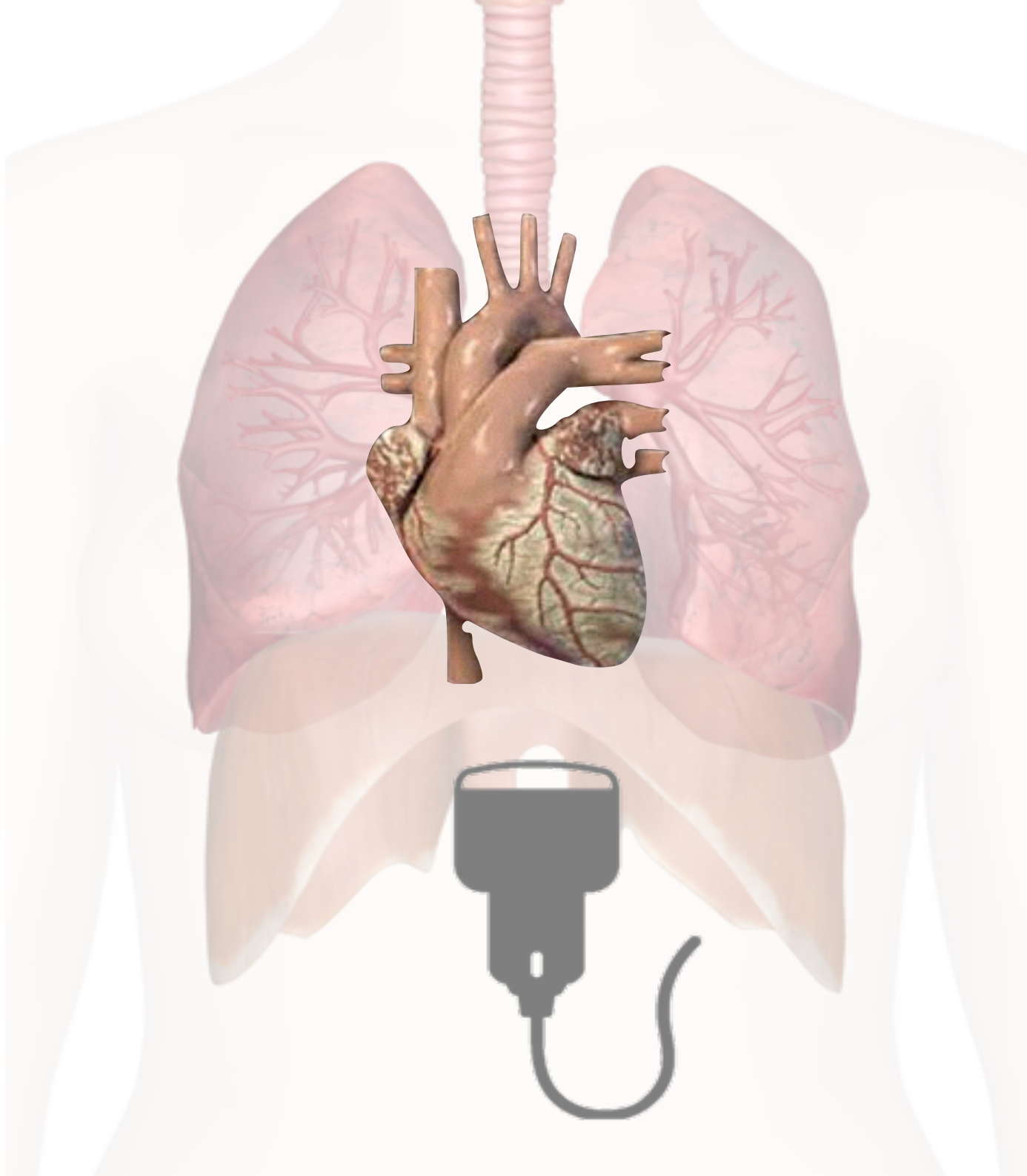
Consolidation

	N	B1	B2	C
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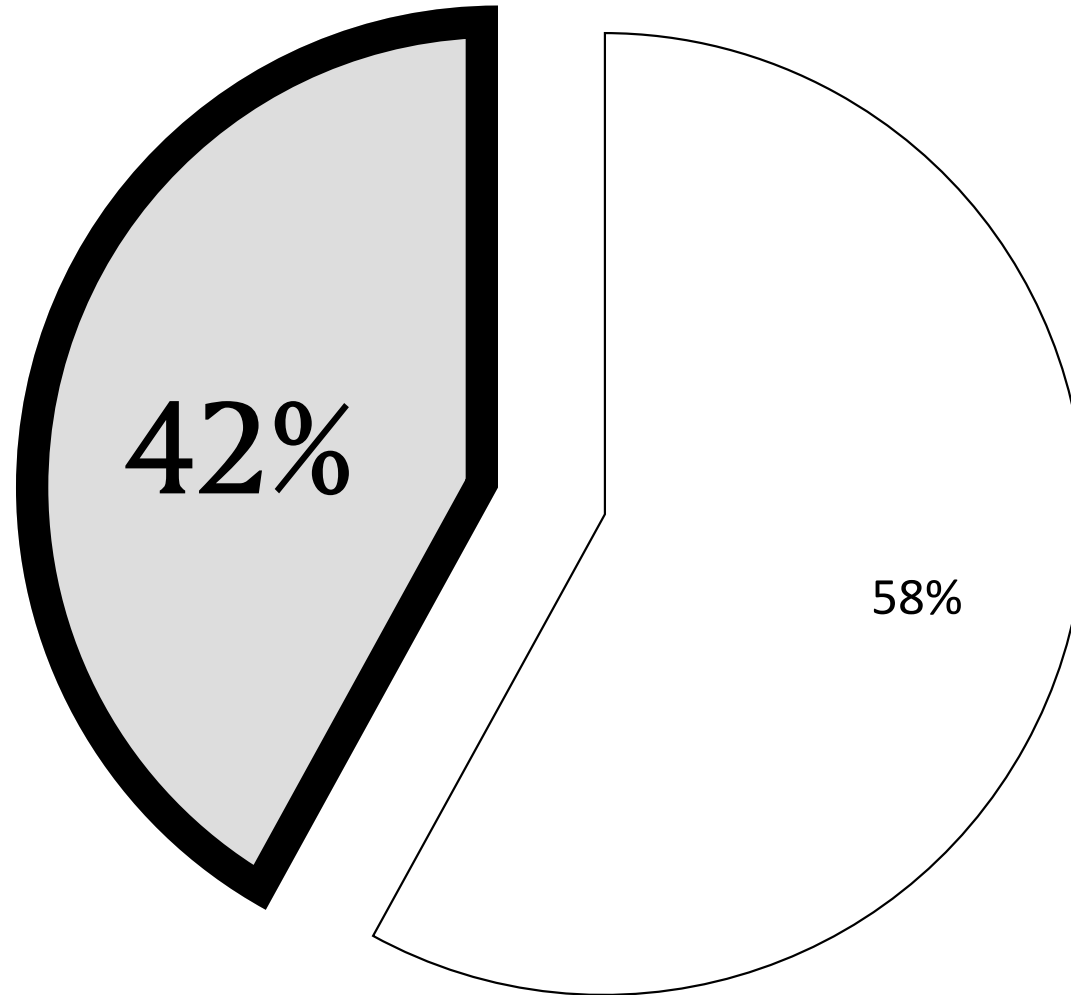
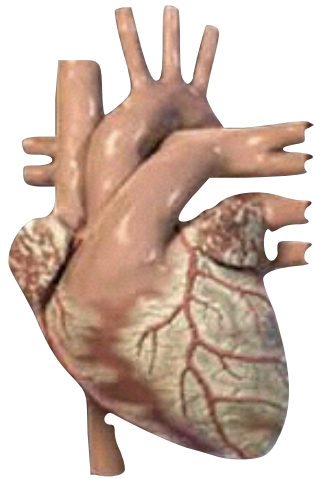
12 area

# Predict weaning failure

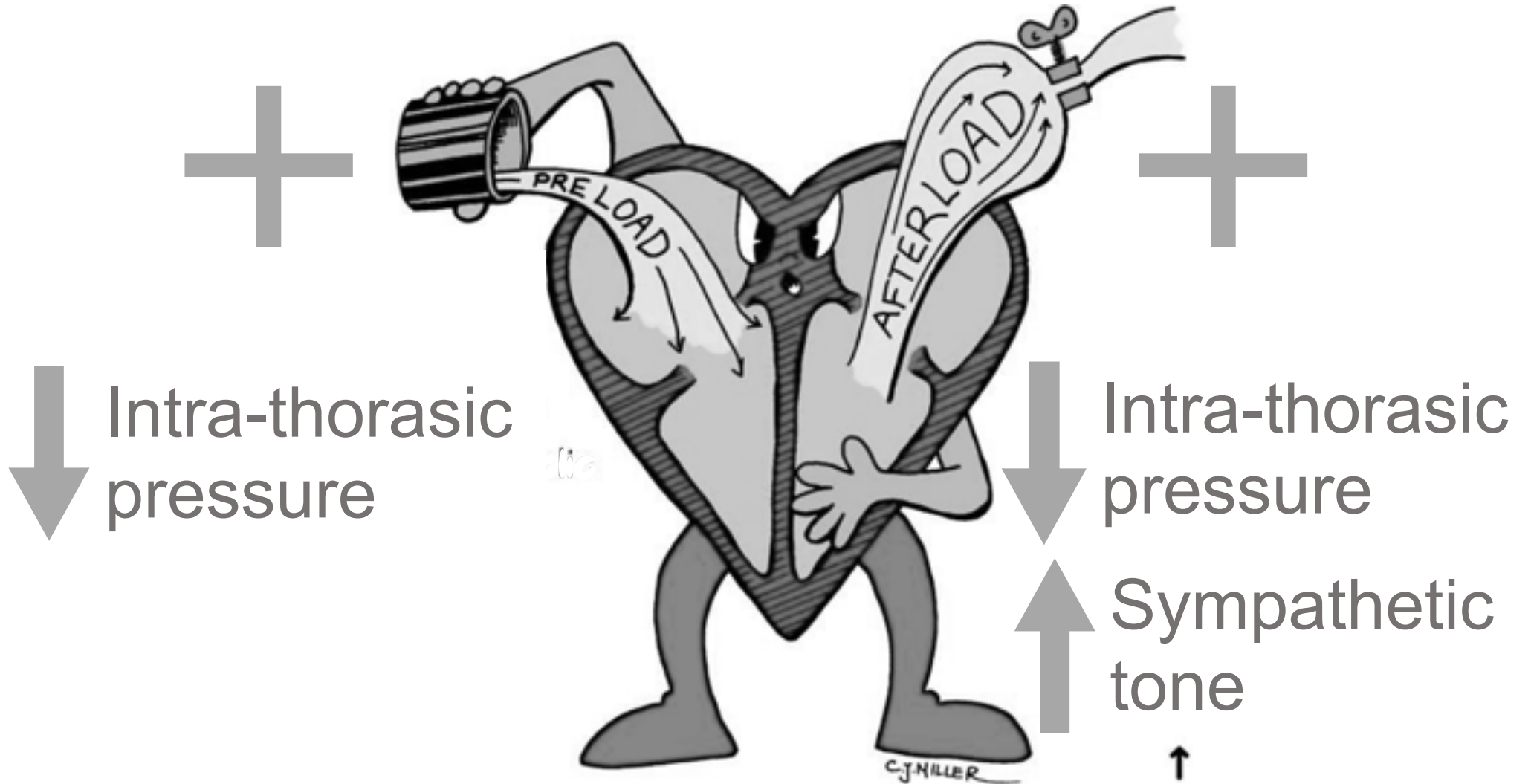




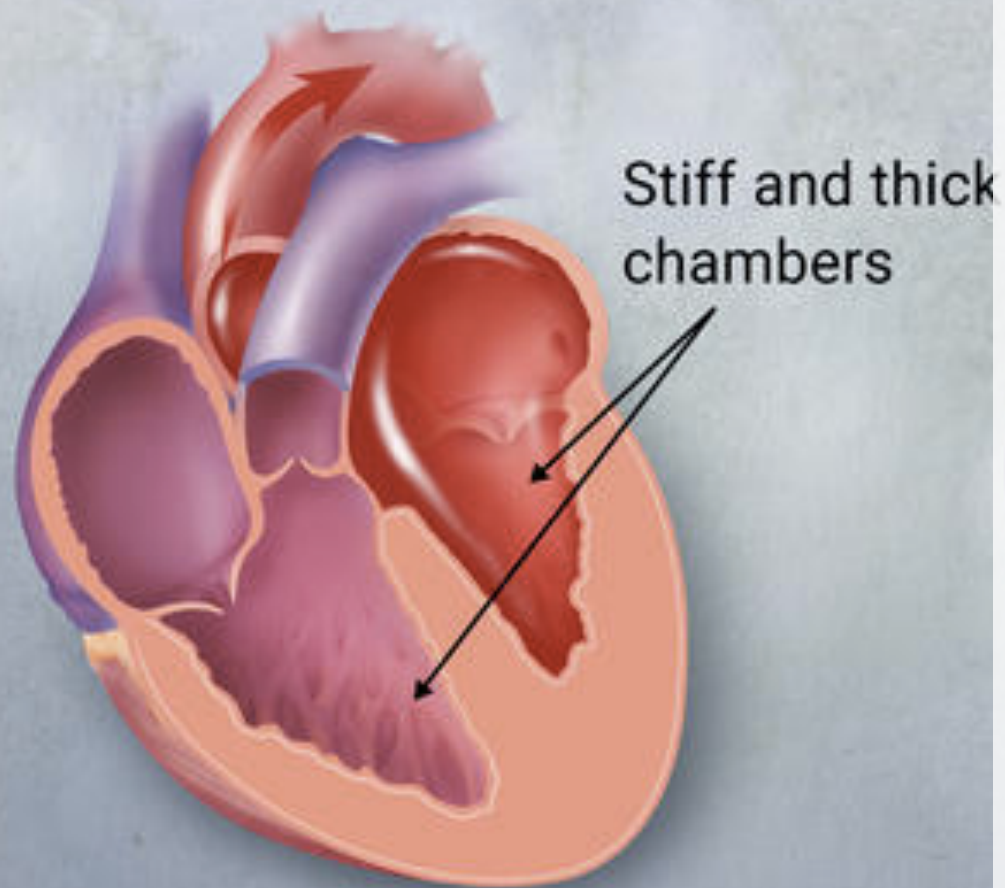
# Cardiac related weaning failure



# Weaning induce cardiac failure

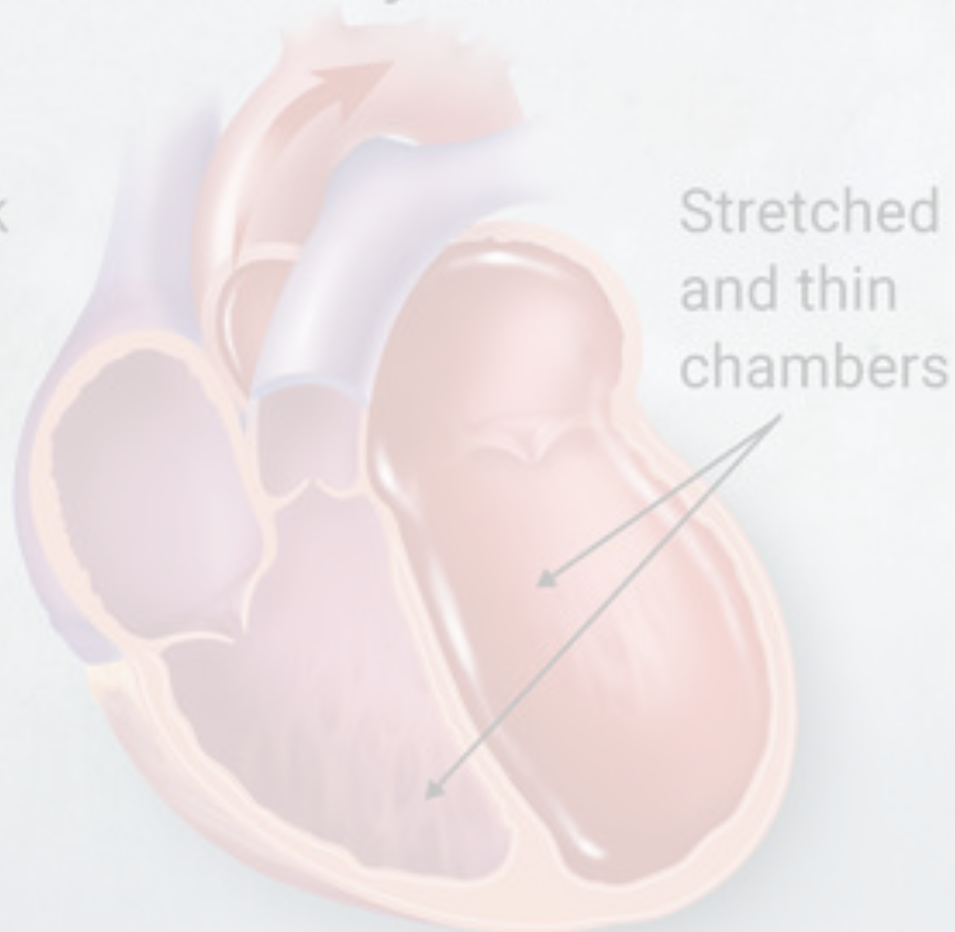


Diastolic

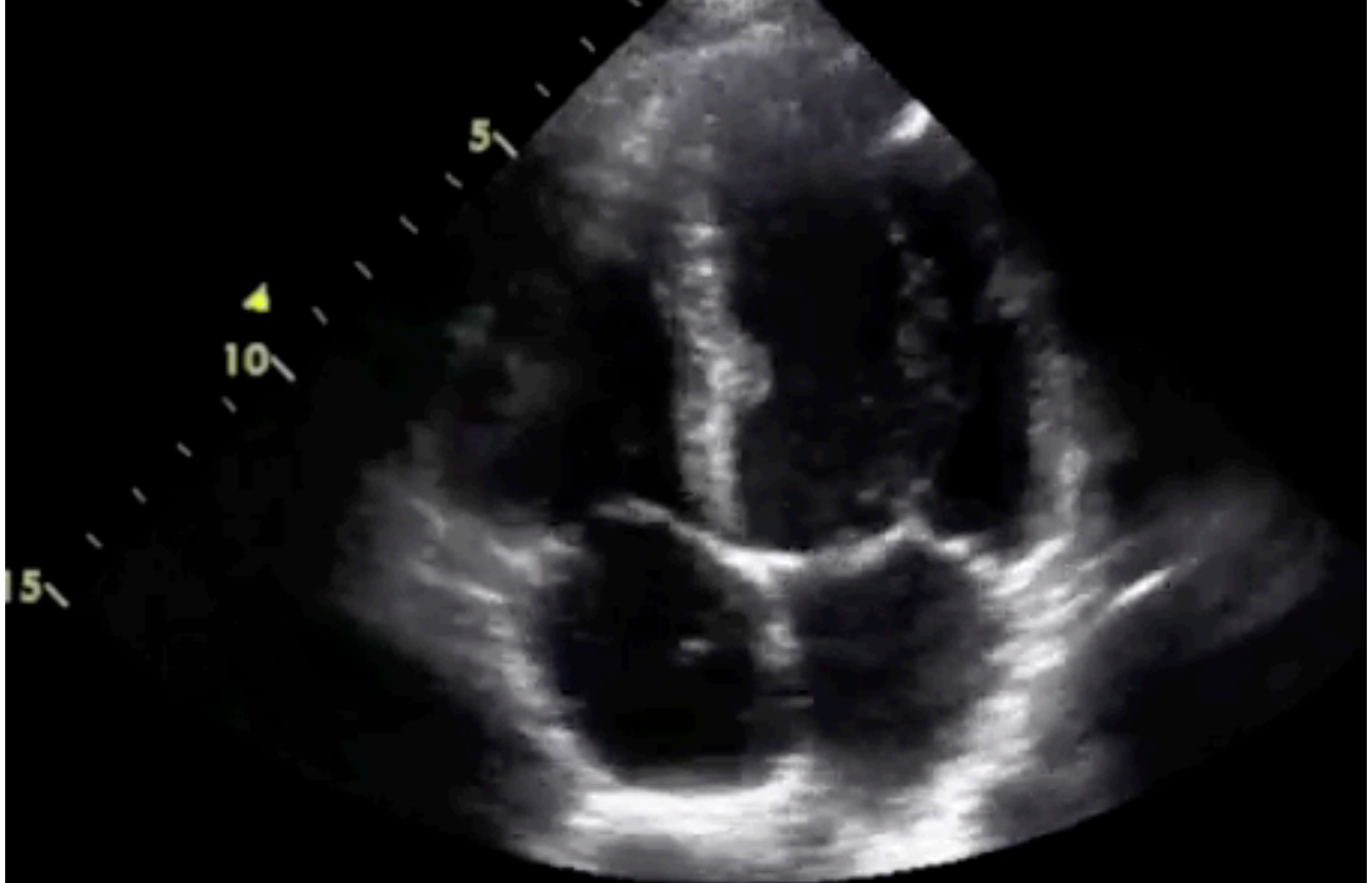


Heart can't fill

Systolic



Heart can't pump



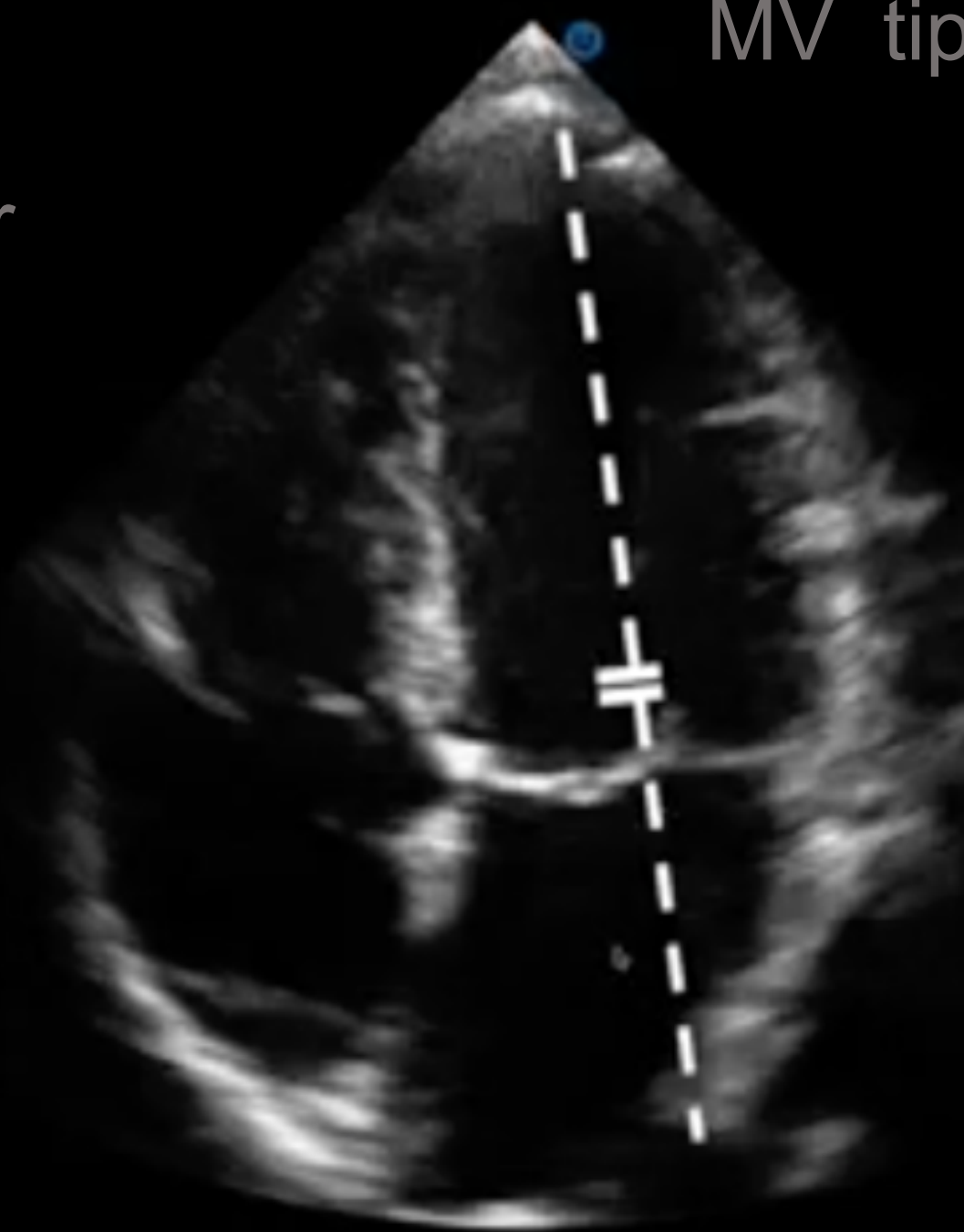
Apical 4 chamber

ICMteaching

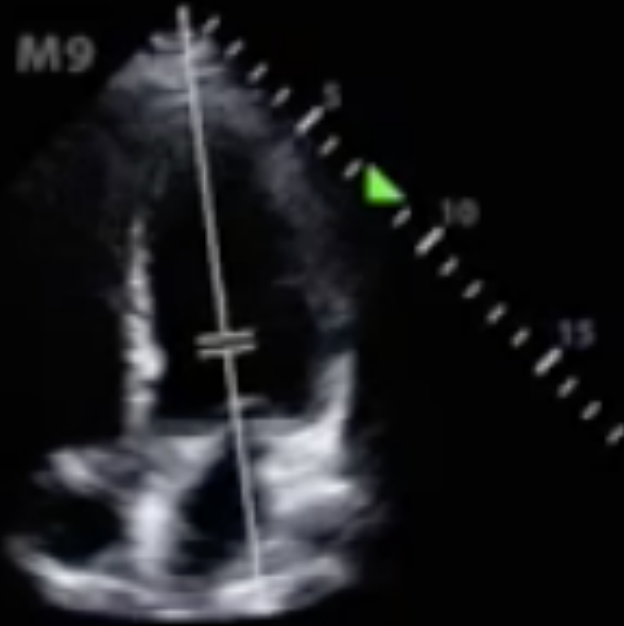


- Pulsed wave Doppler (PWD)

MV tip 1-3mm



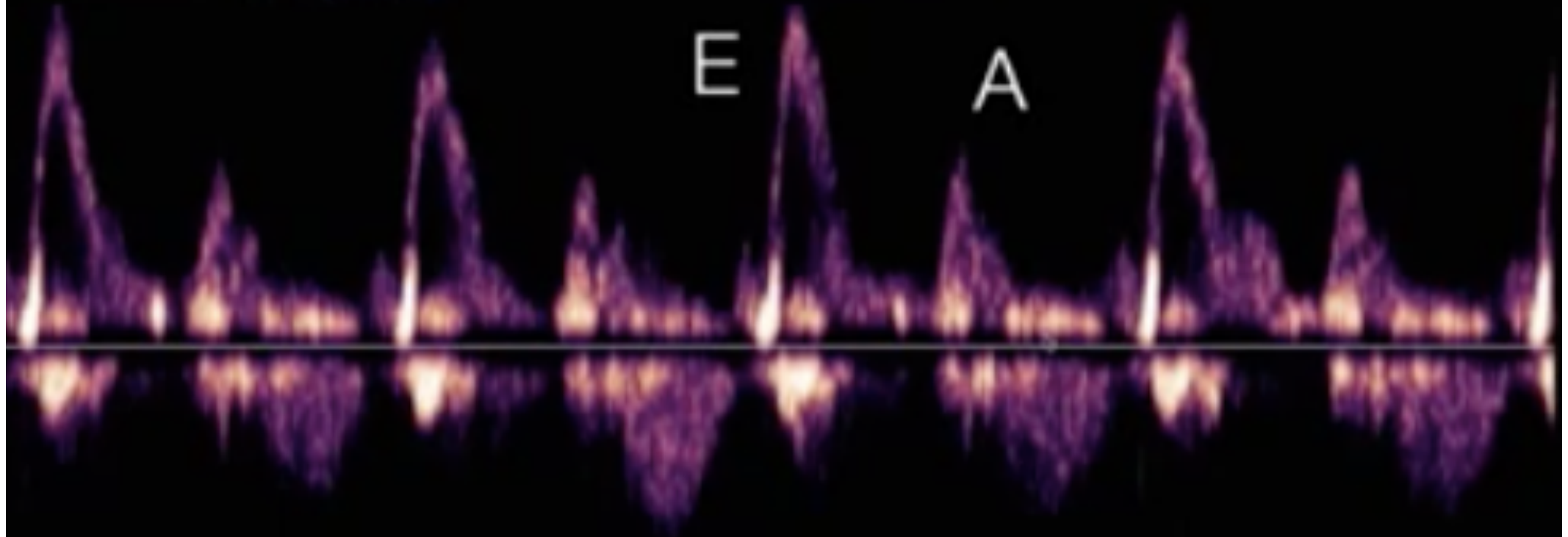
P 96.6% MI 0.5 TIS 0.7



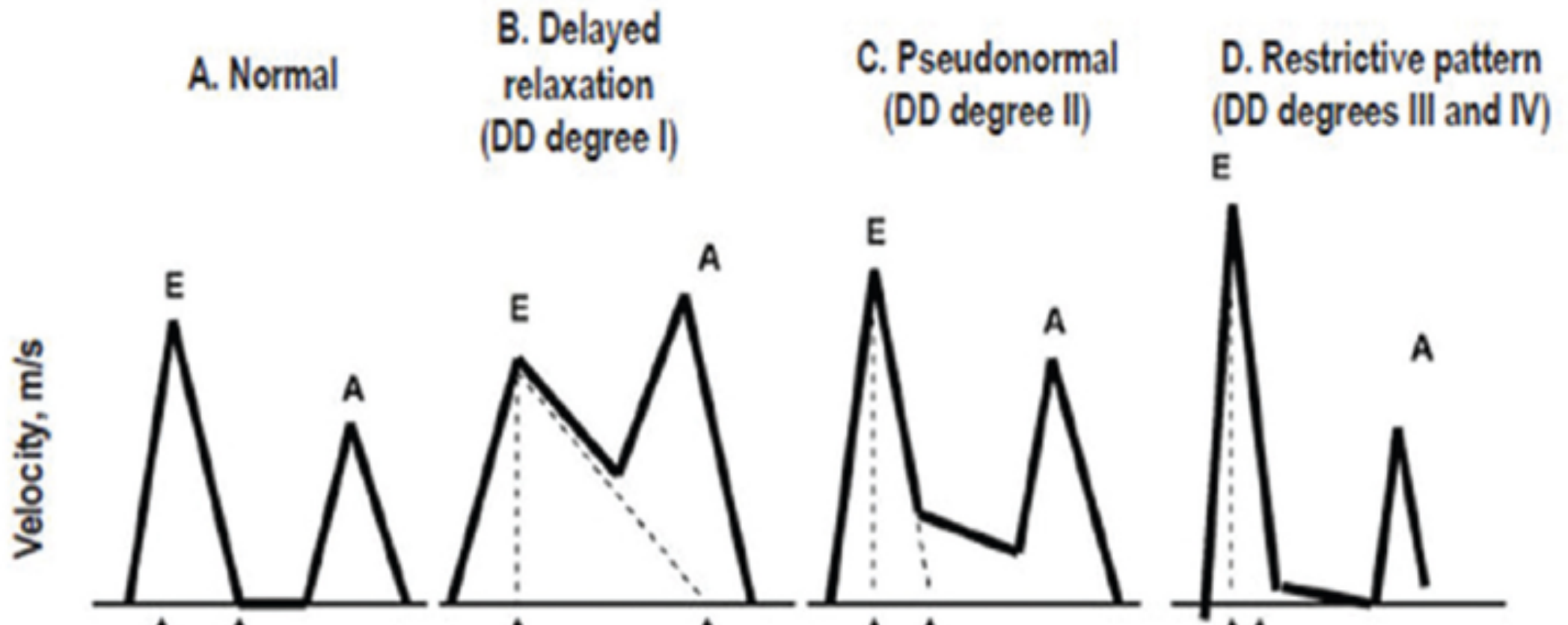
E: Early rapid filling

A: Atrial kick

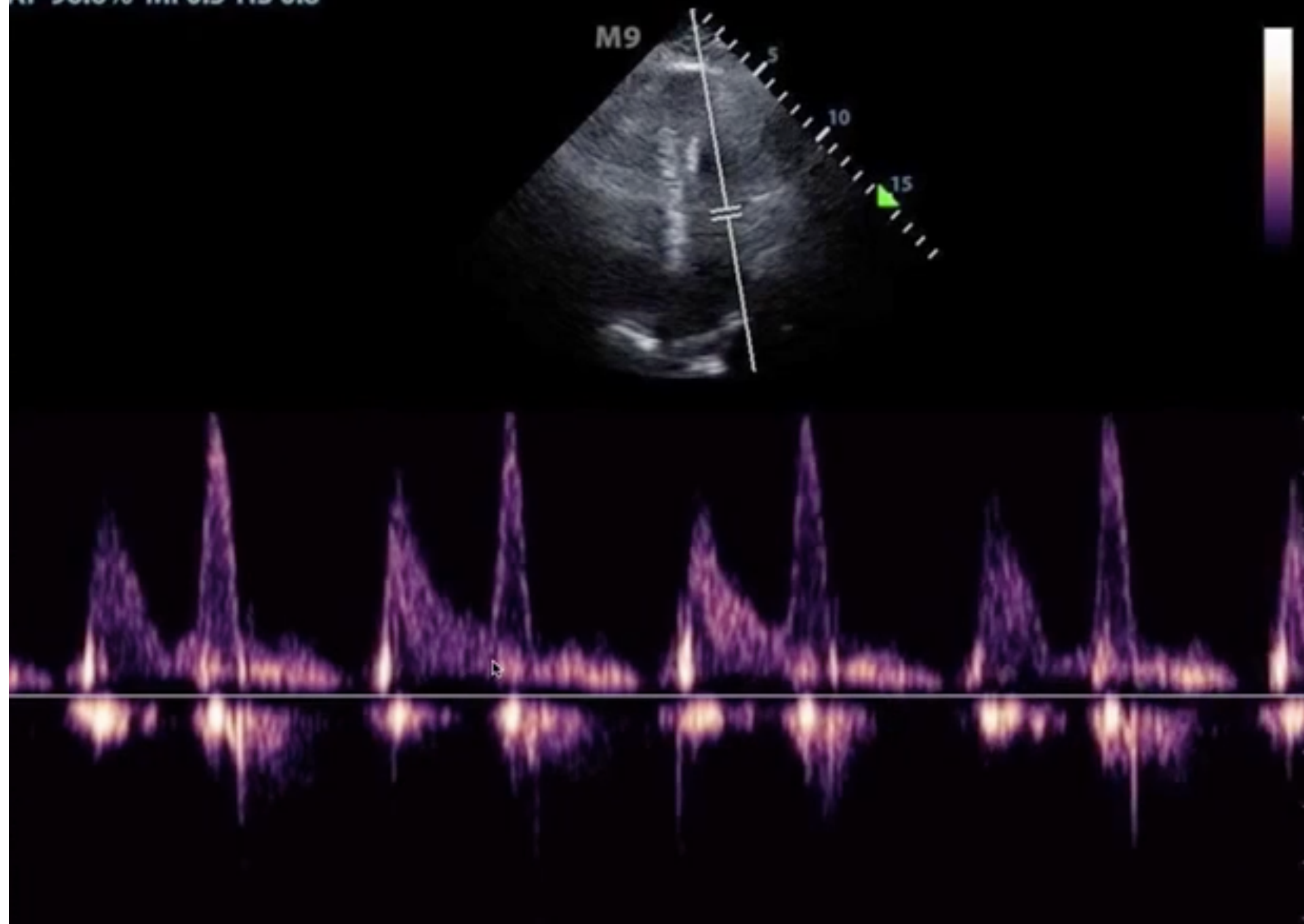
862/862

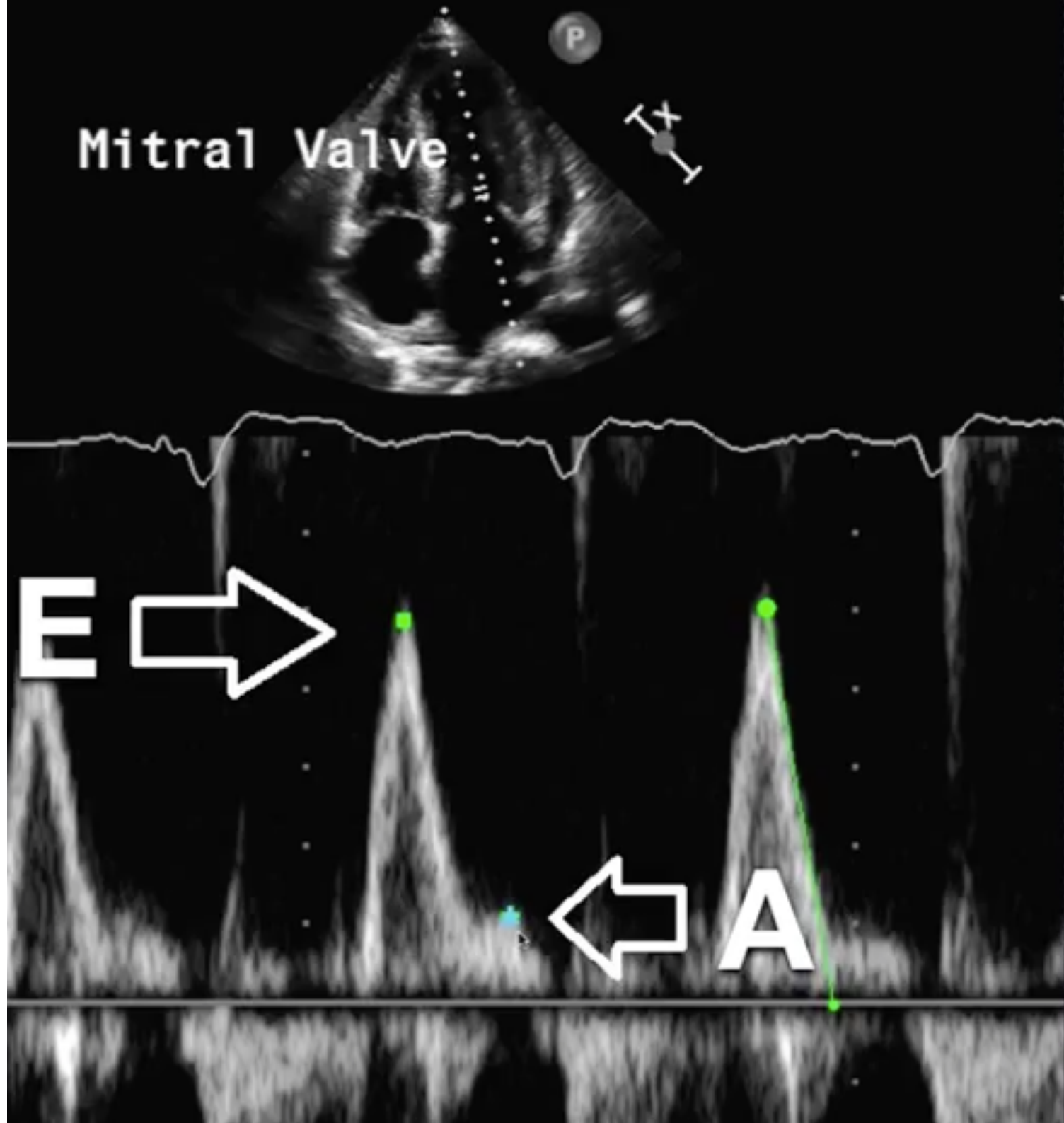


# Grading of diastolic cardiac failure

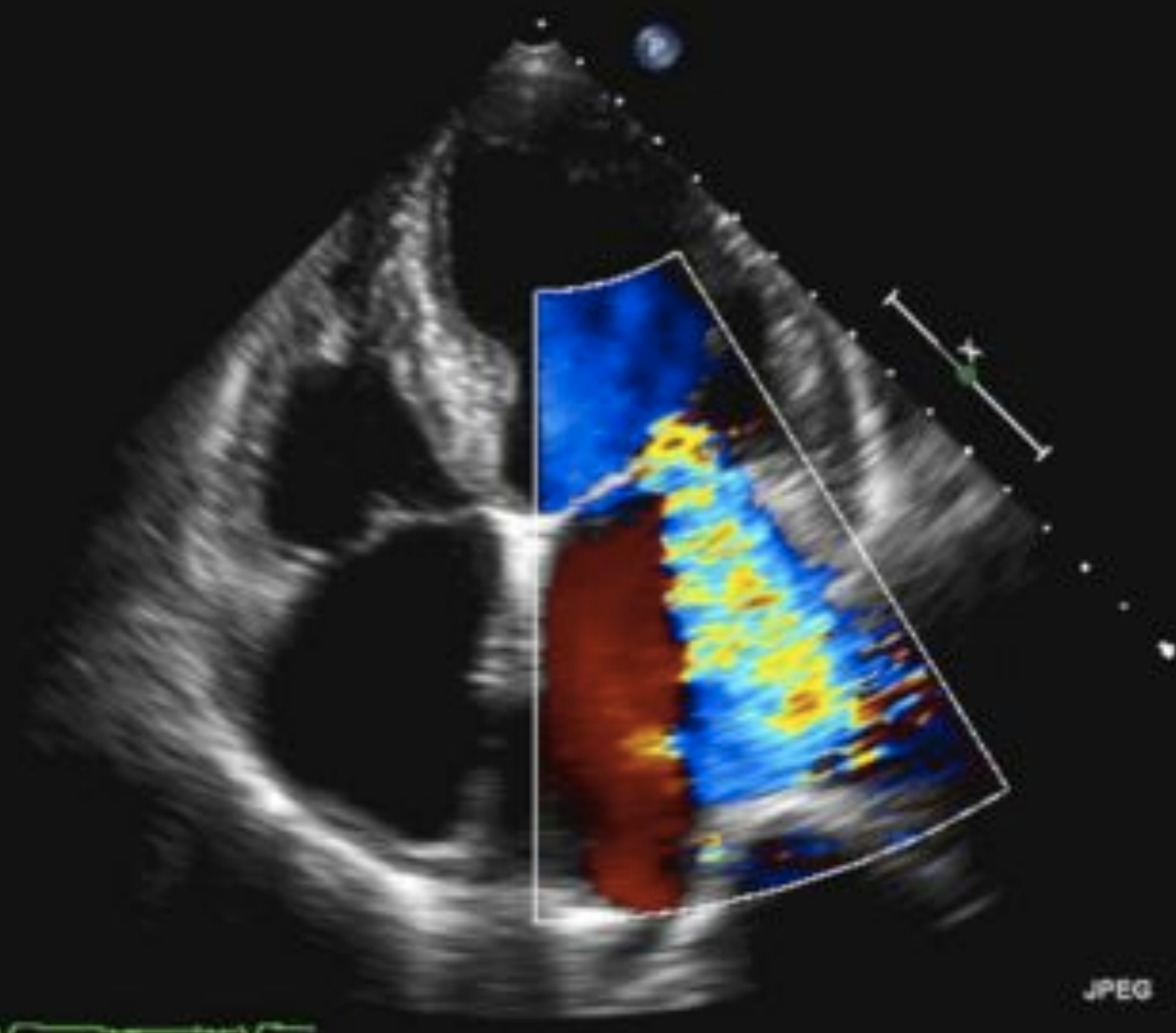


AP 96.6% MI 0.5 TIS 0.8





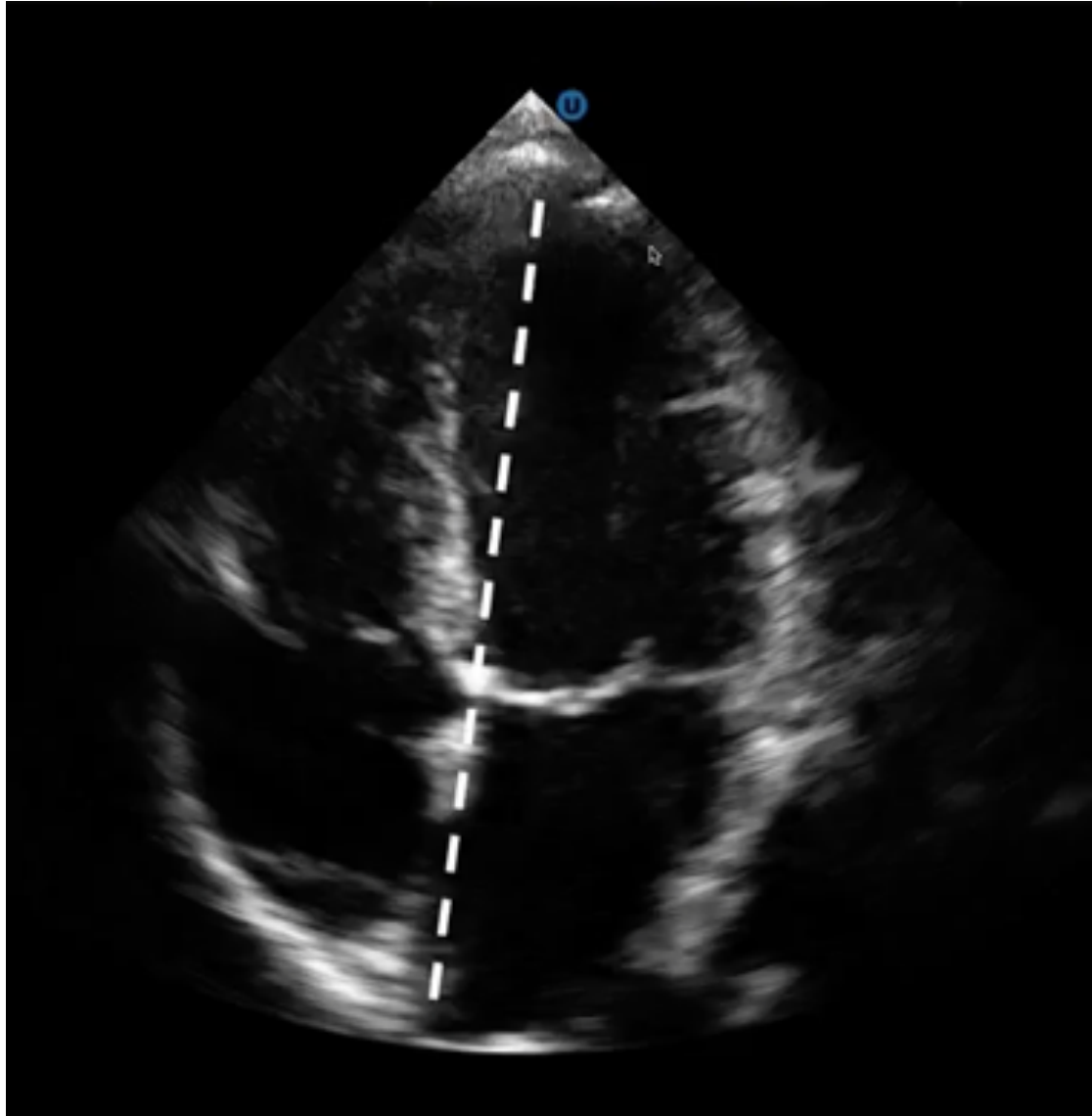
137177



JPEG



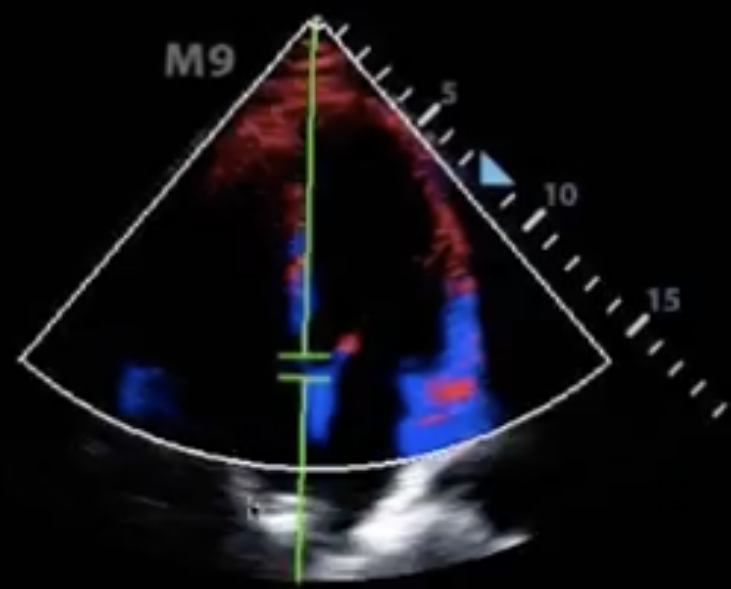
# Differentiating Normal vs Pseudo-normal



Tissue  
Doppler  
Imaging  
(TDI)

P 96.6% MI 0.1 TIS 0.9

Septal

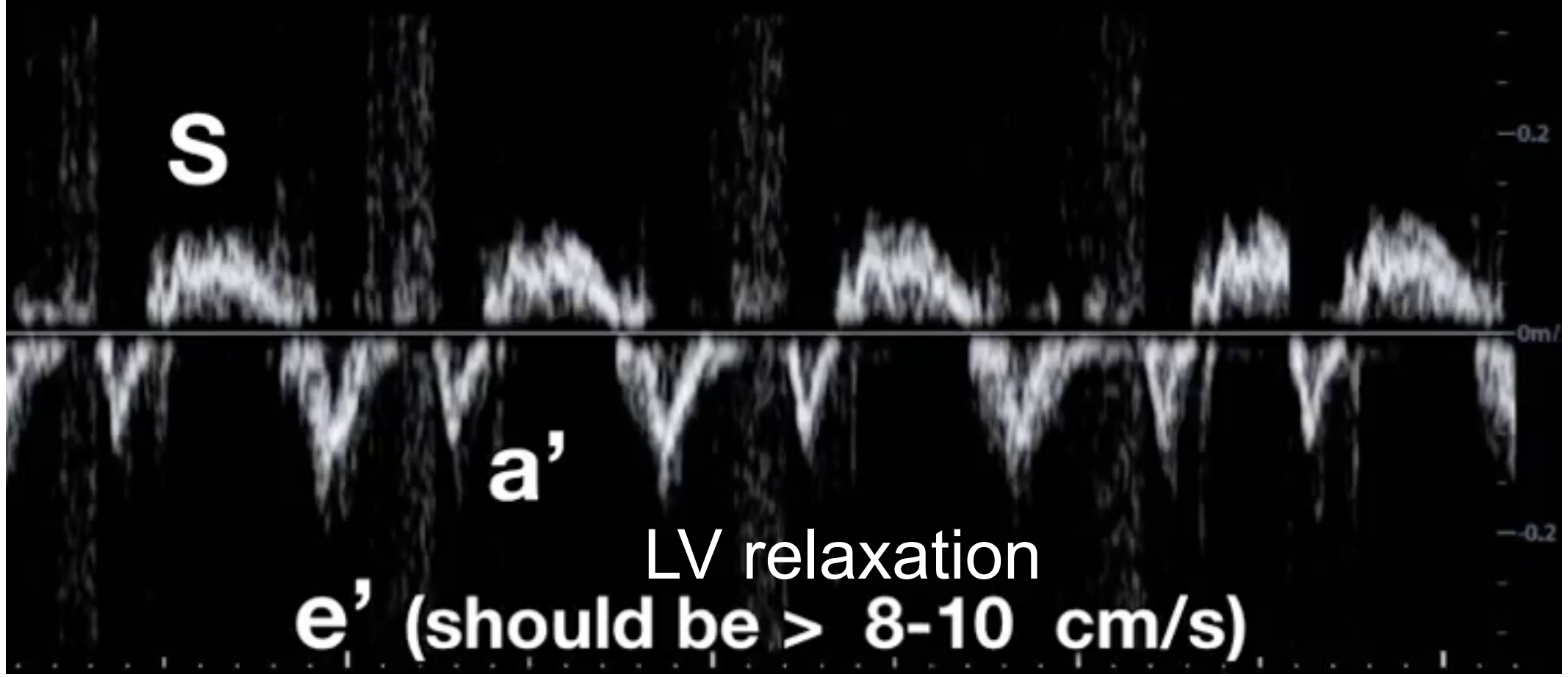


S

a'

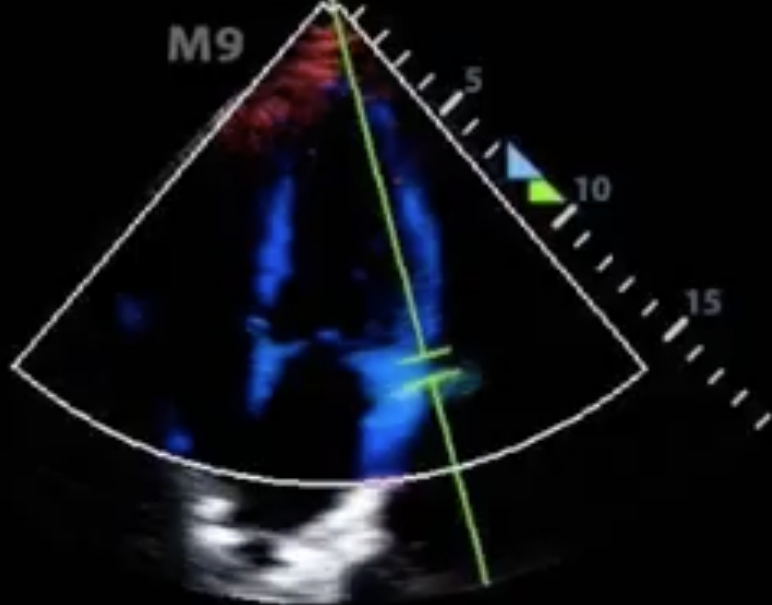
LV relaxation

e' (should be  $> 8-10$  cm/s)





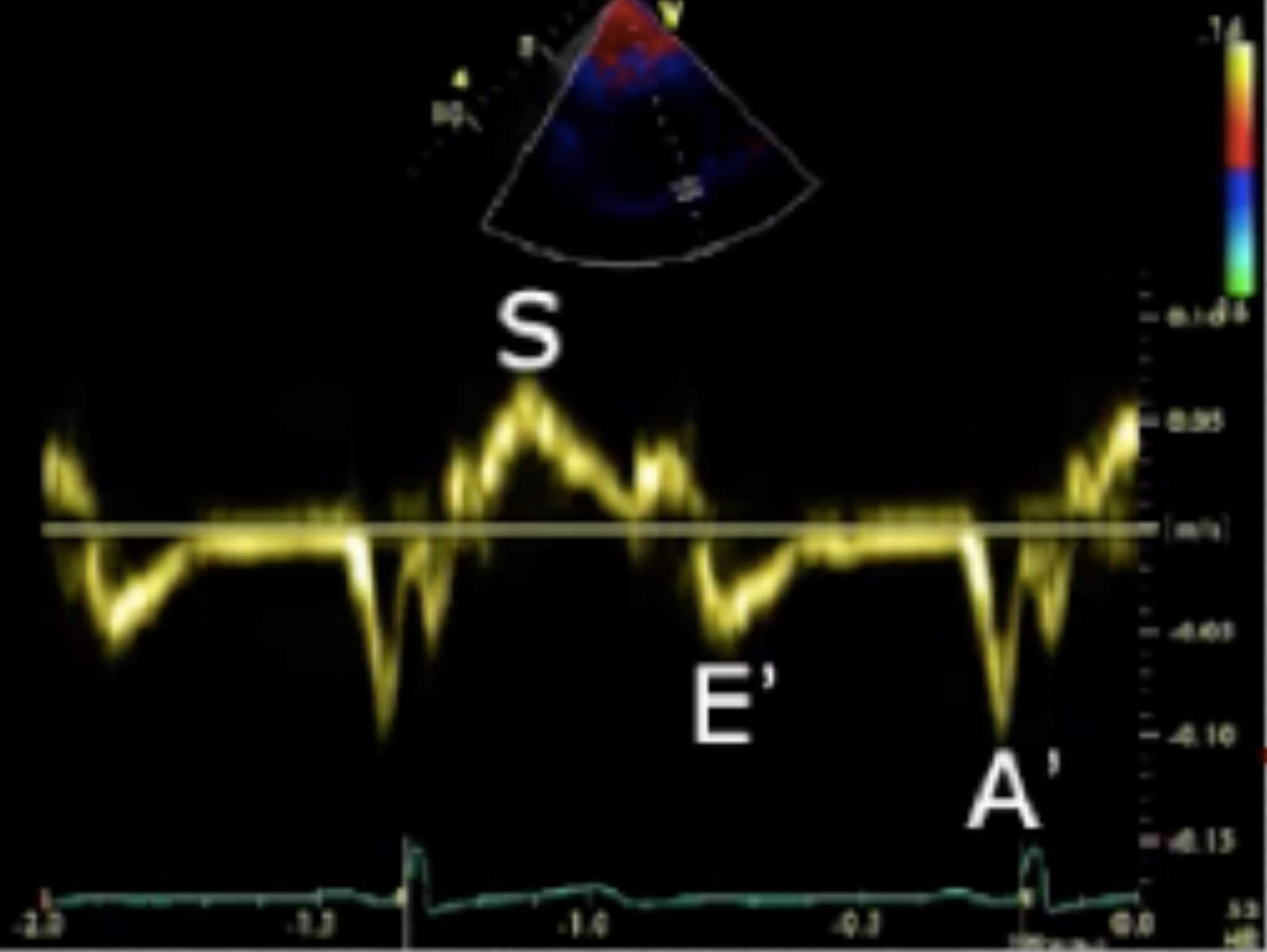
Lateral



S

a'

e' (should be > 12 cm/s)



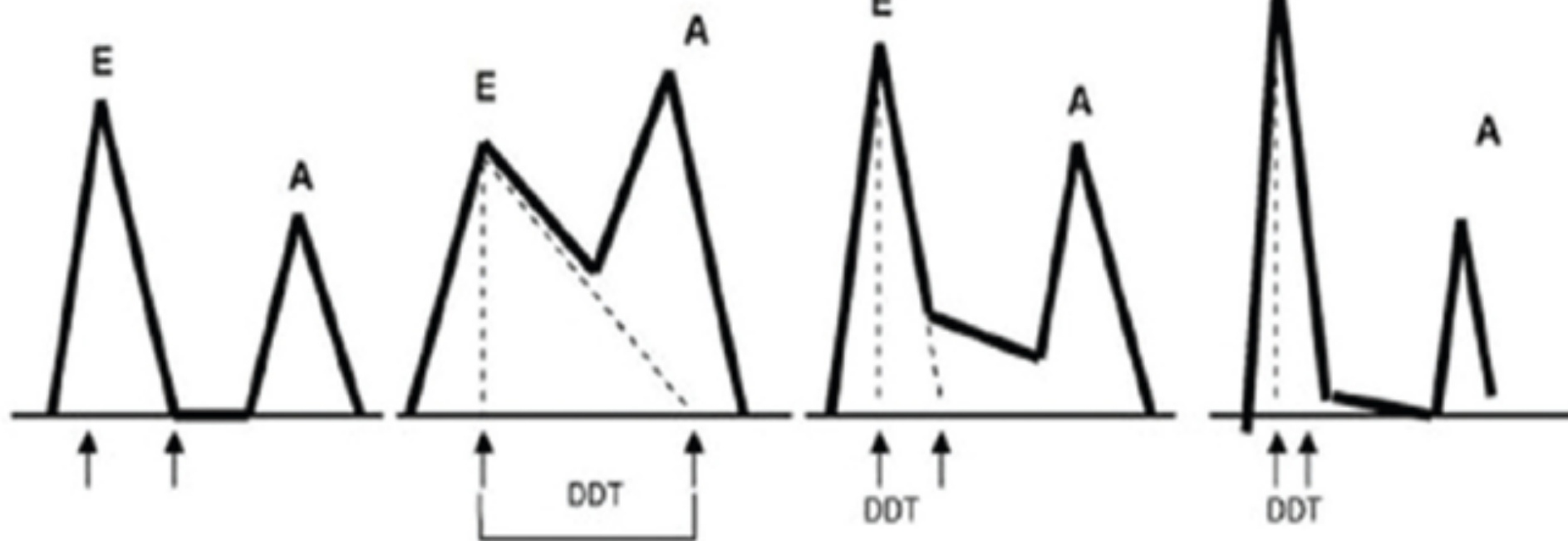
A. Normal

B. Delayed relaxation  
(DD degree I)

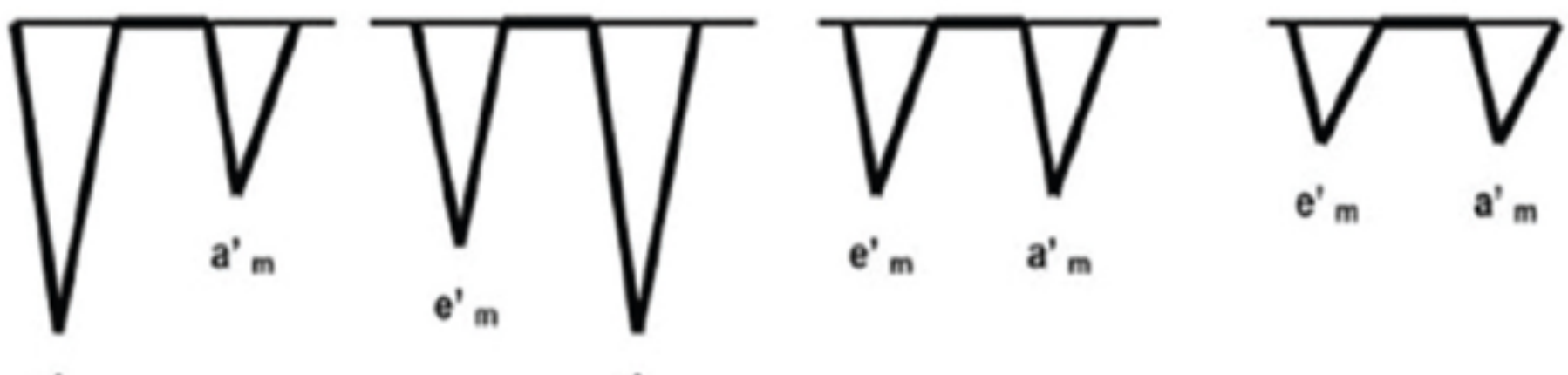
C. Pseudonormal  
(DD degree II)

D. Restrictive pattern  
(DD degrees III and IV)


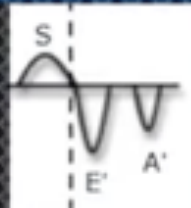

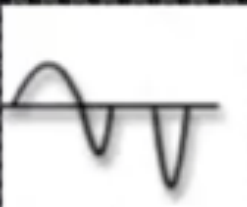

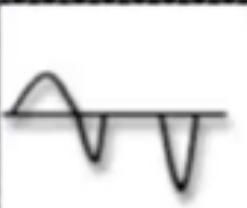

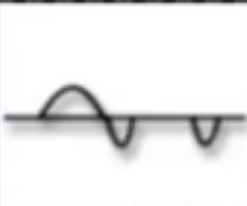
Velocity, m/s



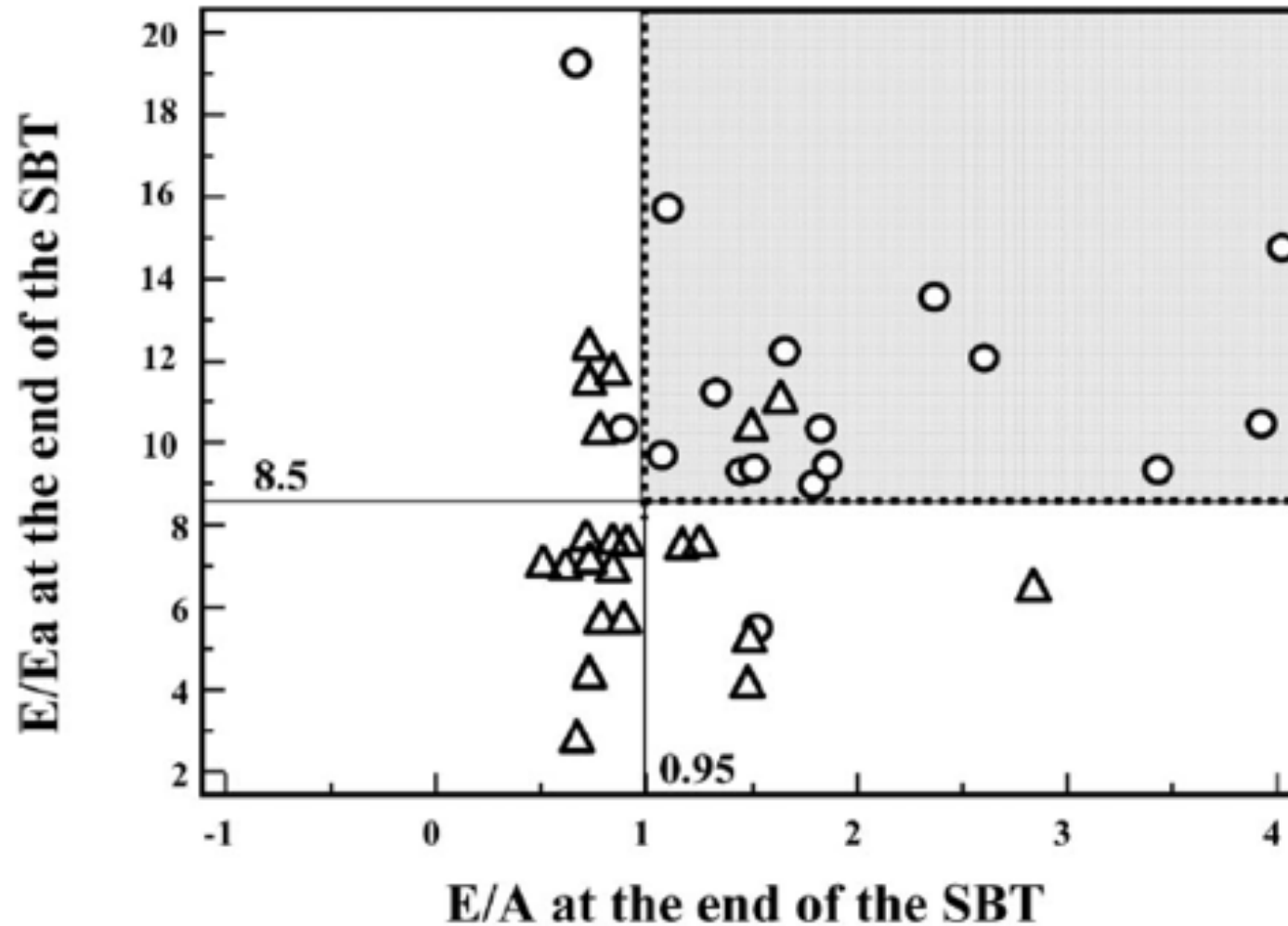
Velocity, m/s



# LVEDP

	E - A Ratio	$e'$ (cm/sec)	$E / e'$
Normal	$E > A$ 	$> 8$ 	$< 8$
Impaired	$A > E$ (2 : 1) 	$< 8$ 	$< 8$
Pseudo-normal	$E > A$ 	$< 8$ 	8 - 15
Restrictive	$E \gg A$ (3 : 1) 	$< 8$ 	$> 15$

# Weaning-induced PAOP elevation.



Sen: 82% Spe:91%

○ PAOP elevation  
△ no PAOP elevation

# Echocardiography for weaning

117 Pt, T tube, before and 30 min



23 PT( 20 cariogenic)

Lower LVEF 36%:51% p=0.04

Higher E/E'(7.0 vs 5.6 p=0.04)

Caille V. Crit Care. 2010;14(3):R120

68 Pt, T tube, before and 10 min

No difference in LVEF

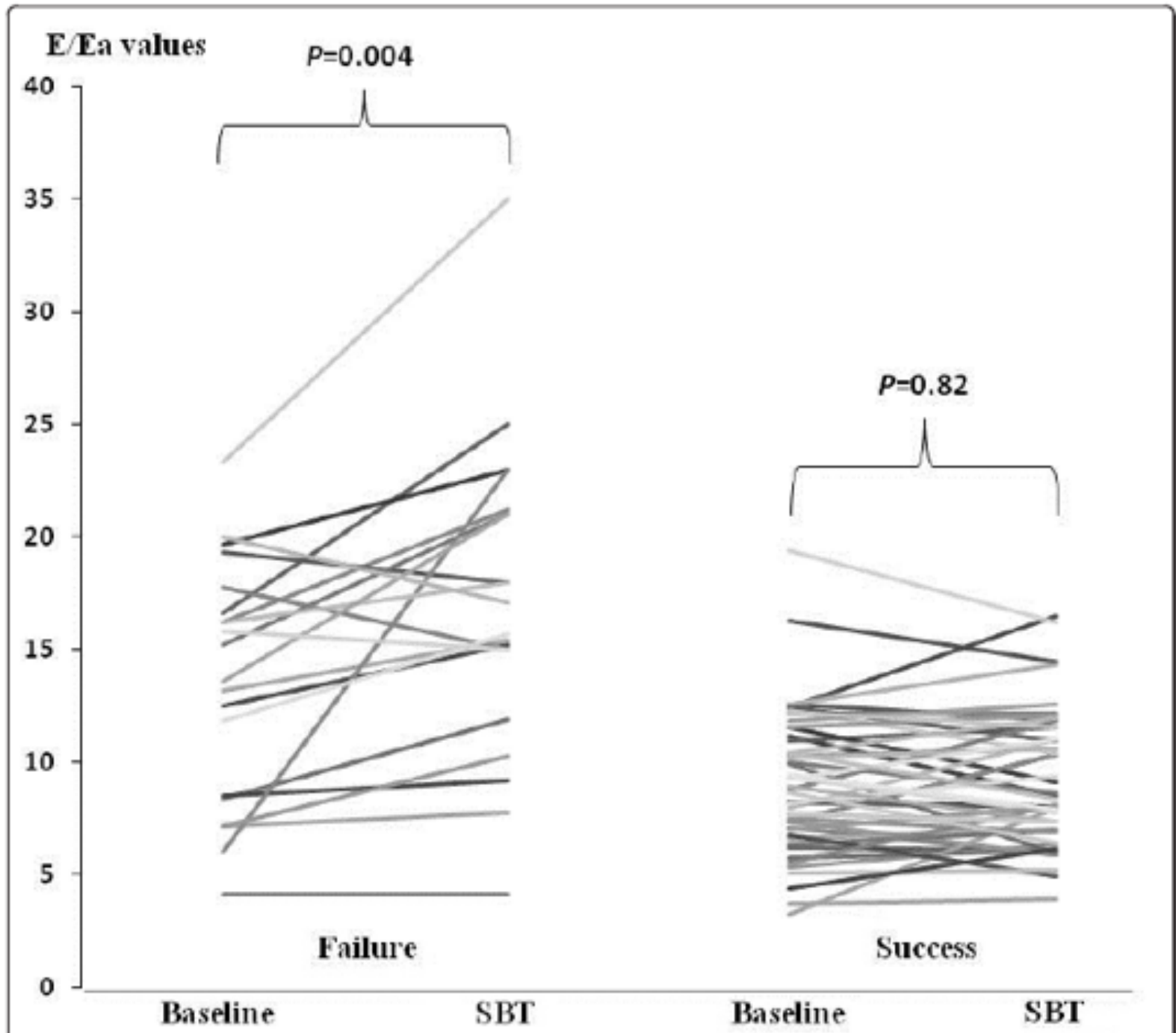


20 PT

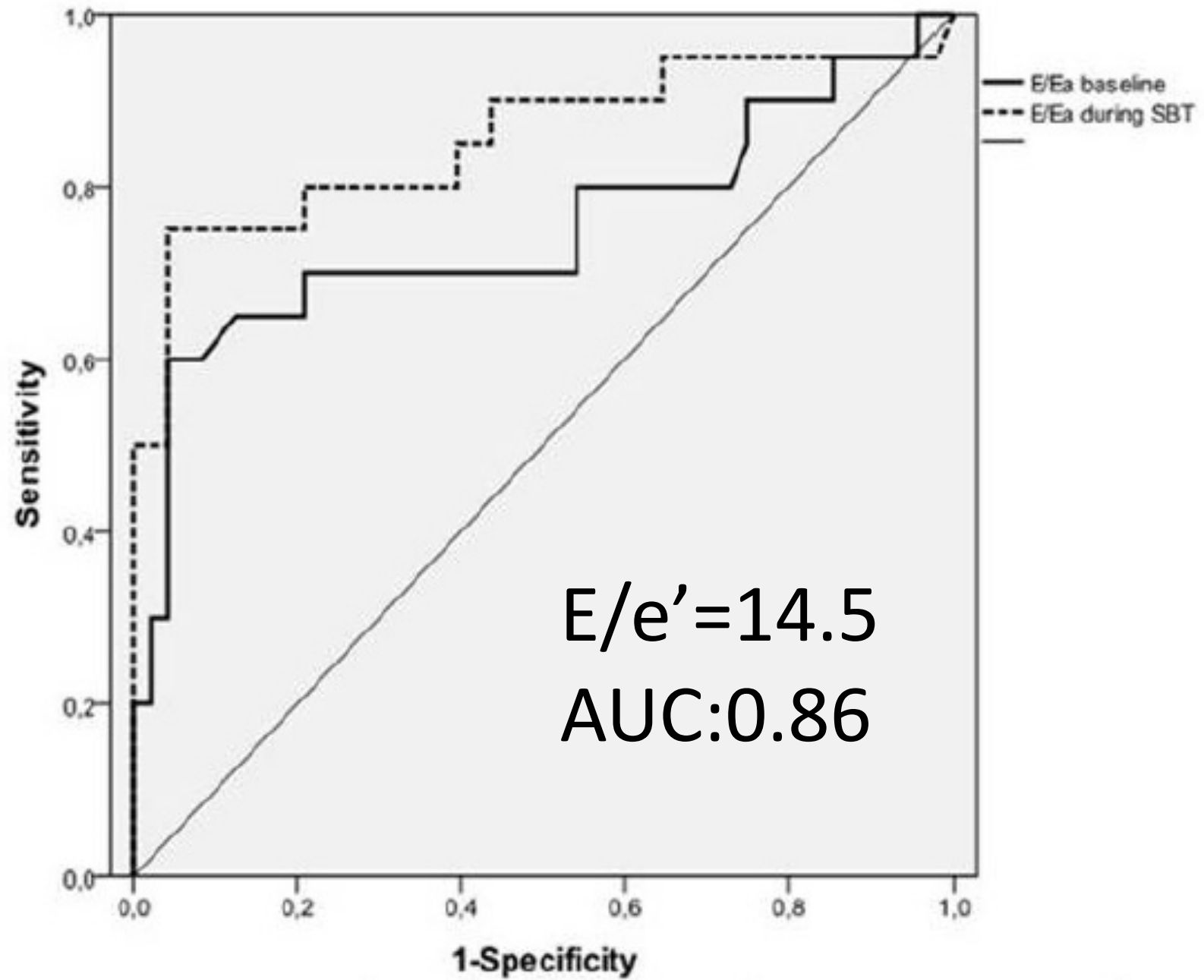
Higher E/e' basal and 10 min

Increasing of E/e'

Moschietto S. Crit Care. 2012 May 14;16(3):R81



**Figure 1** Individual values of E/Ea mitral ratio in the failure and the success group. This figure represents individual values of E/Ea measured at baseline and during SBT for patients in failure group (A) and for patients in the success group (B). Significant increase in E/Ea occurs during SBT in the failure group while no variation in E/Ea is observed in the success group.





# Intolerance of SBT

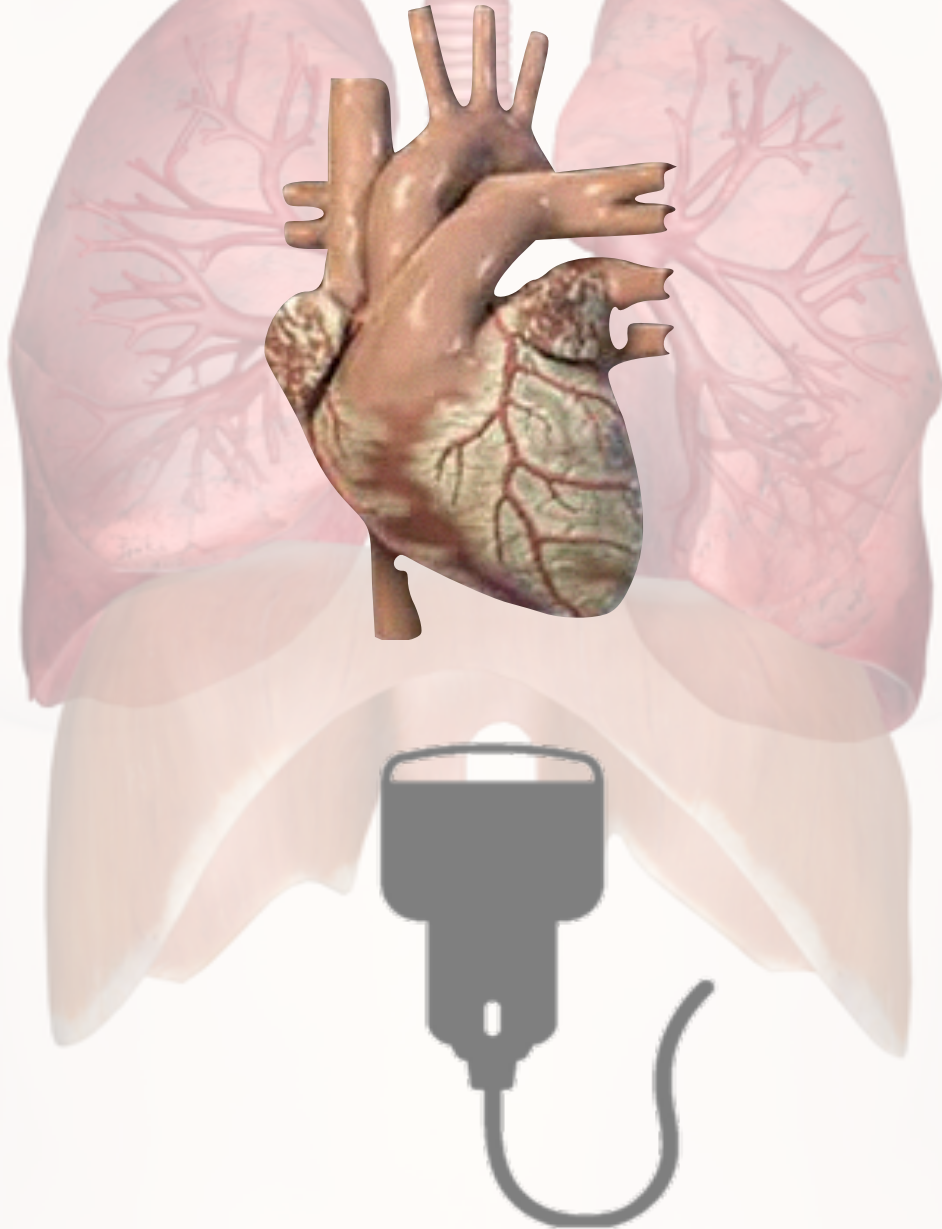
Weaning related HF

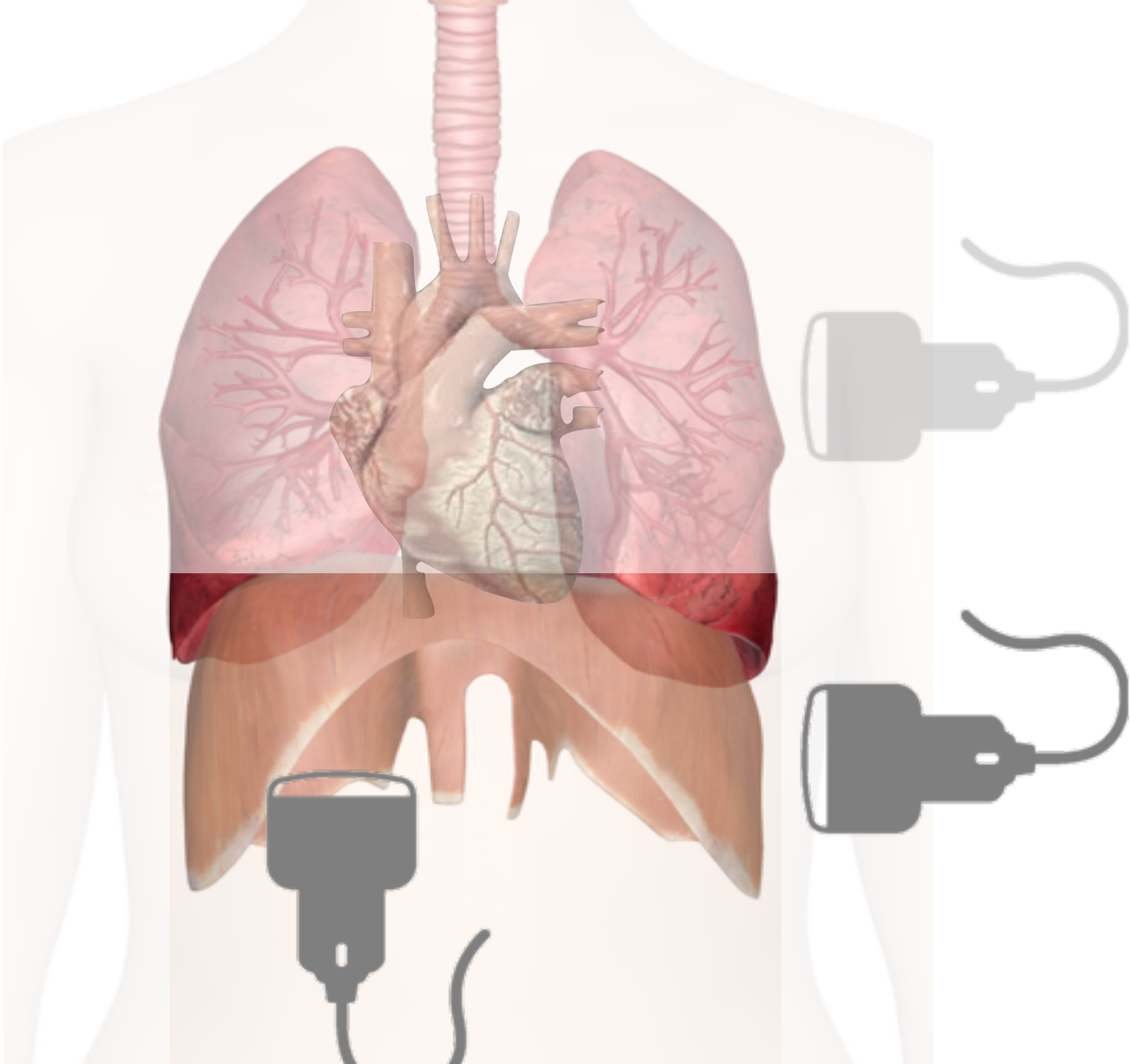
Diastolic heart function

Use PWD and TDI

E/e' good predictor

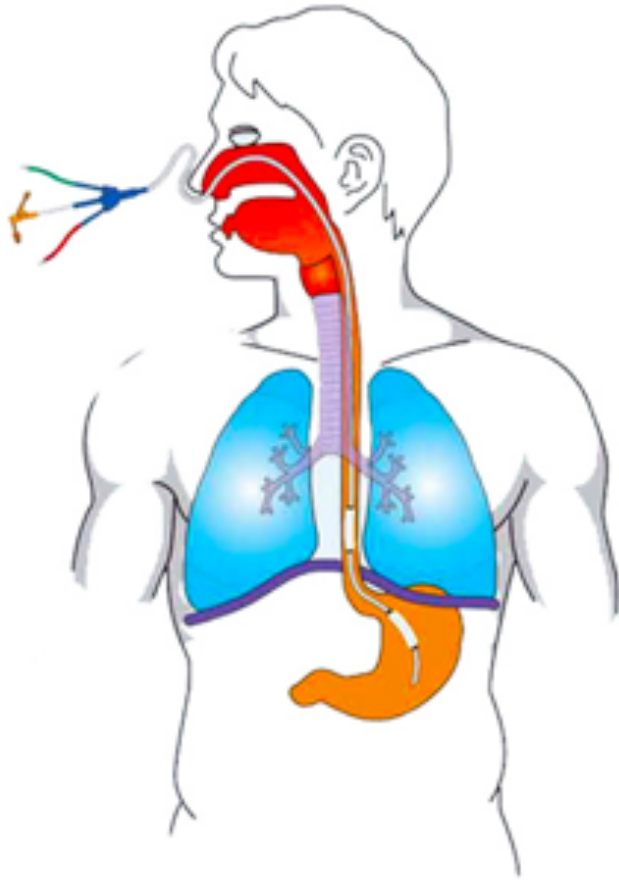
Bedside, different time





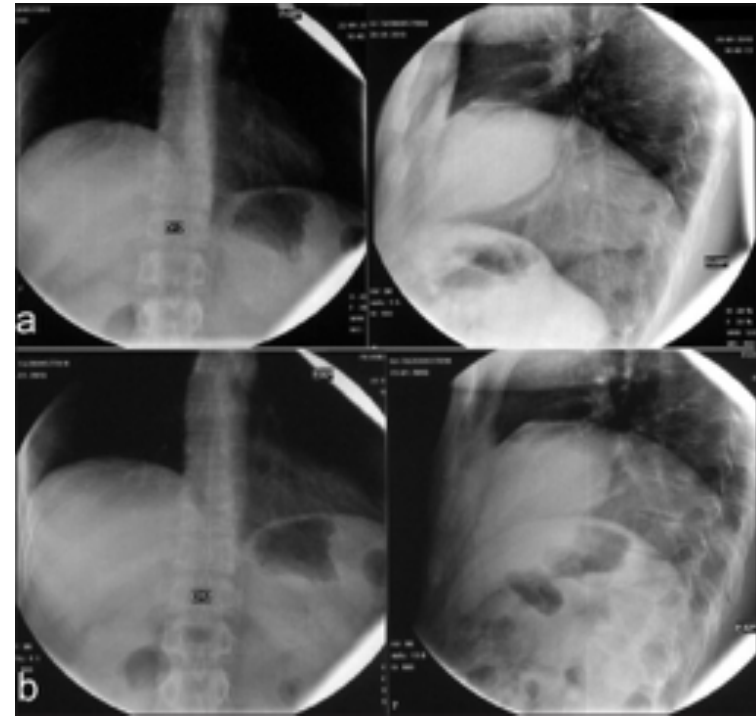
# Evaluation of Diaphragm motion

- Transdiaphragmatic pressure ( $P_{Di}$ )



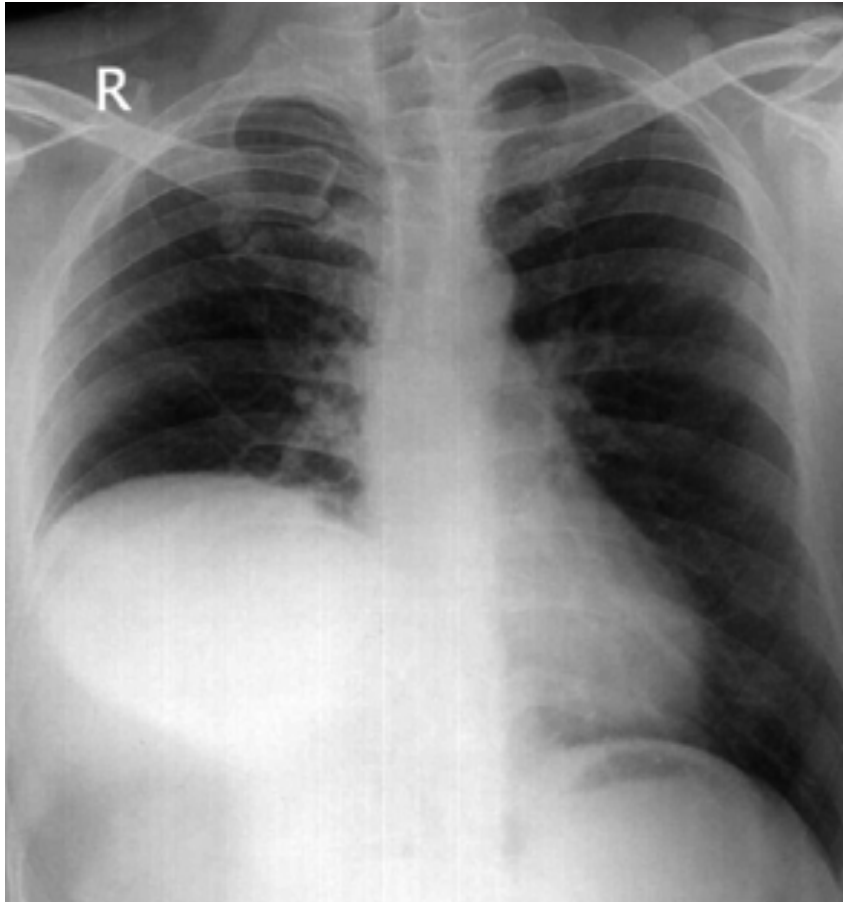
Gold standard for bilateral paralysis

- Fluoroscopic sniff test



Higher false negative

- CXR



For unilateral paralysis  
Sen: 90%; Spe: 44%

- Pulm function test



Needs pt cooperation

# Diaphragm ultrasonography (DU)

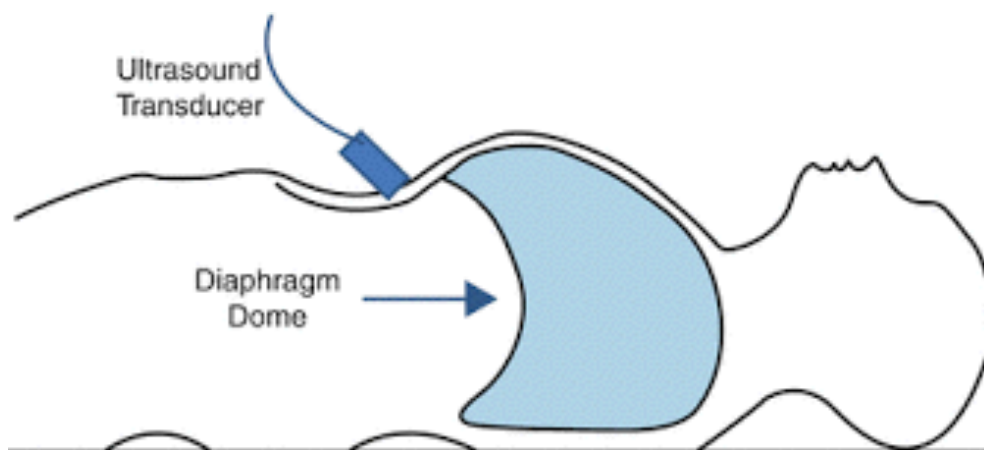
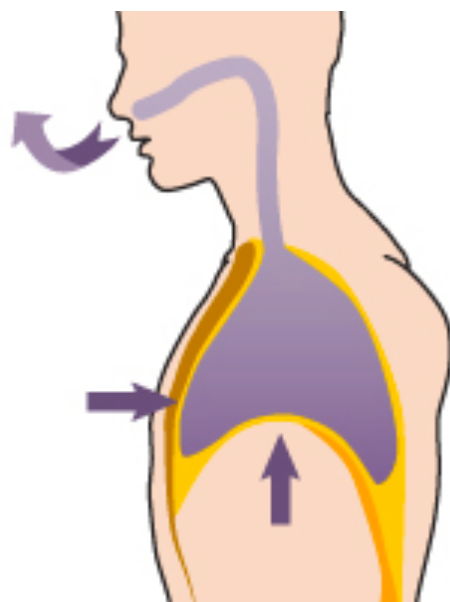
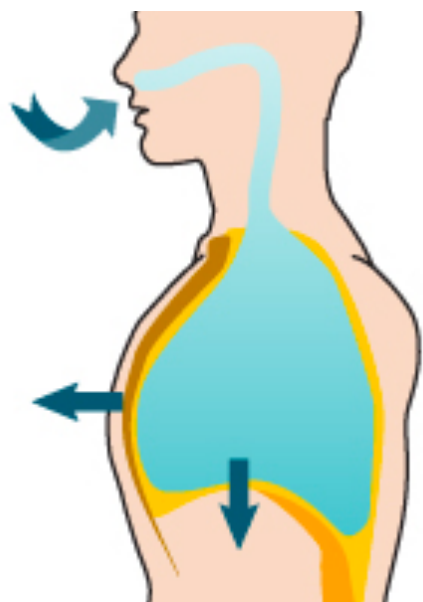
## **Morphology** and **function** assessment



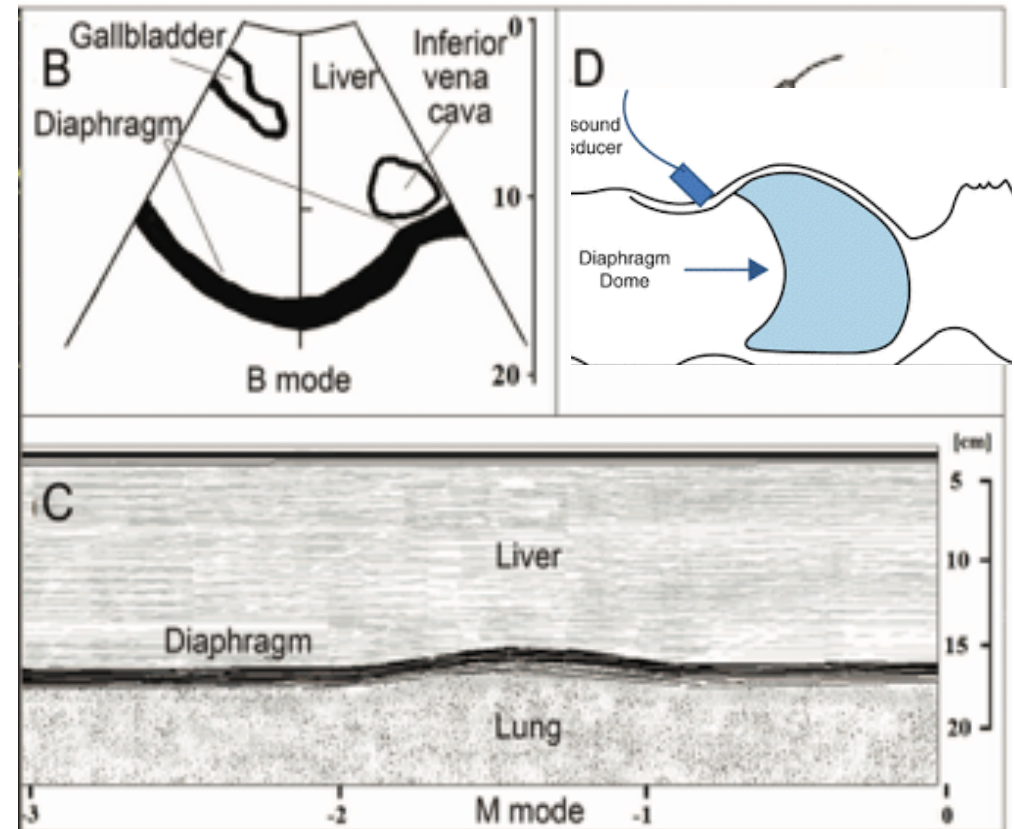
- Paradoxical movement



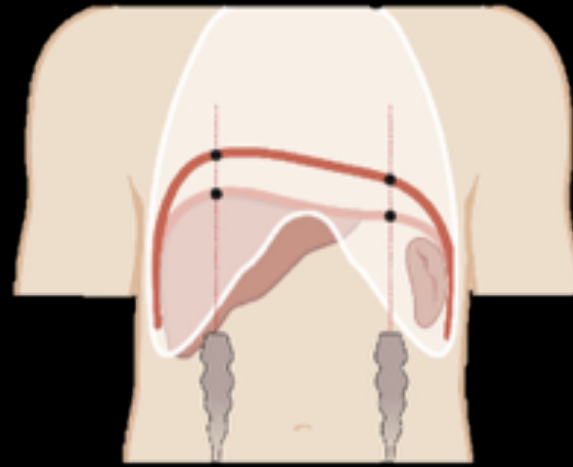
- Thickness of diaphragm (Tdi)
- Thickening fraction
- Inspiratory excursion



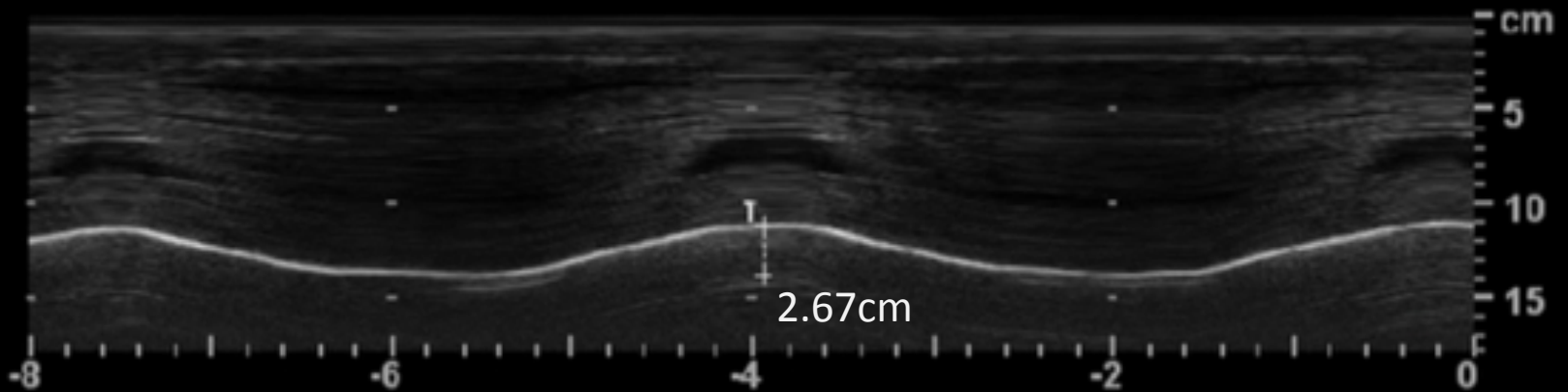
# Inspiratory excursion



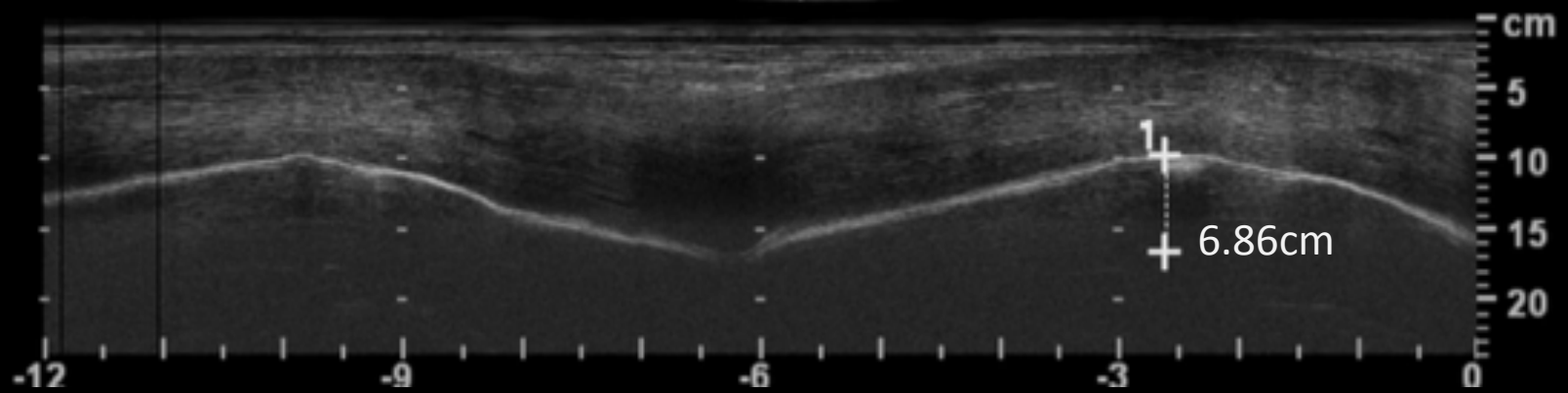
- Array probe
- Midclavian line
- Subcostal area



**Normal breathing**

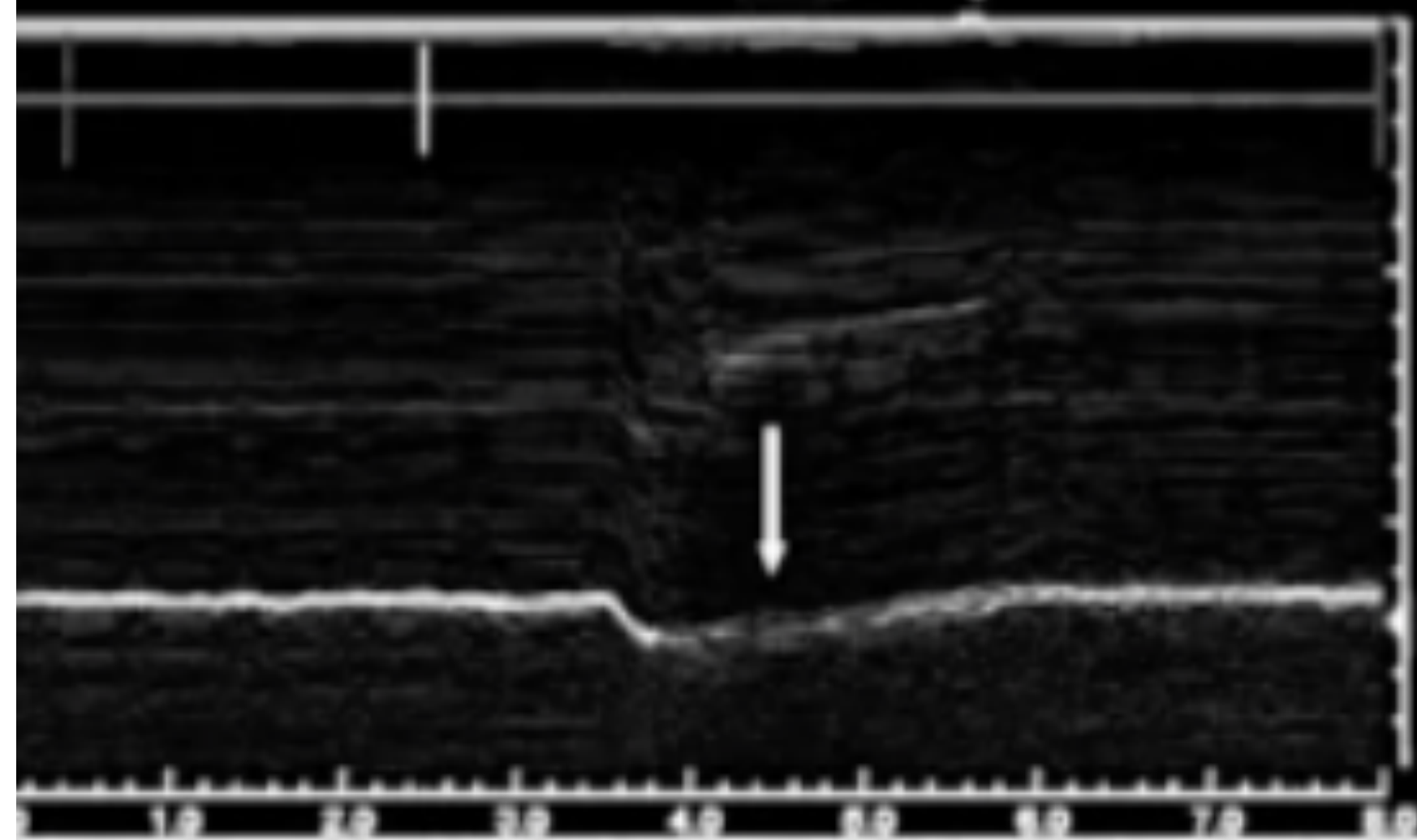


**Deep breathing**





ZD: 18 cm  
31 7%  
F: 1.7 MHz H  
DR: 68 dB  
R: 4.0 G: 47  
M O: 49



F: 0.48  
T1s: 0.3  
M1: 1.8

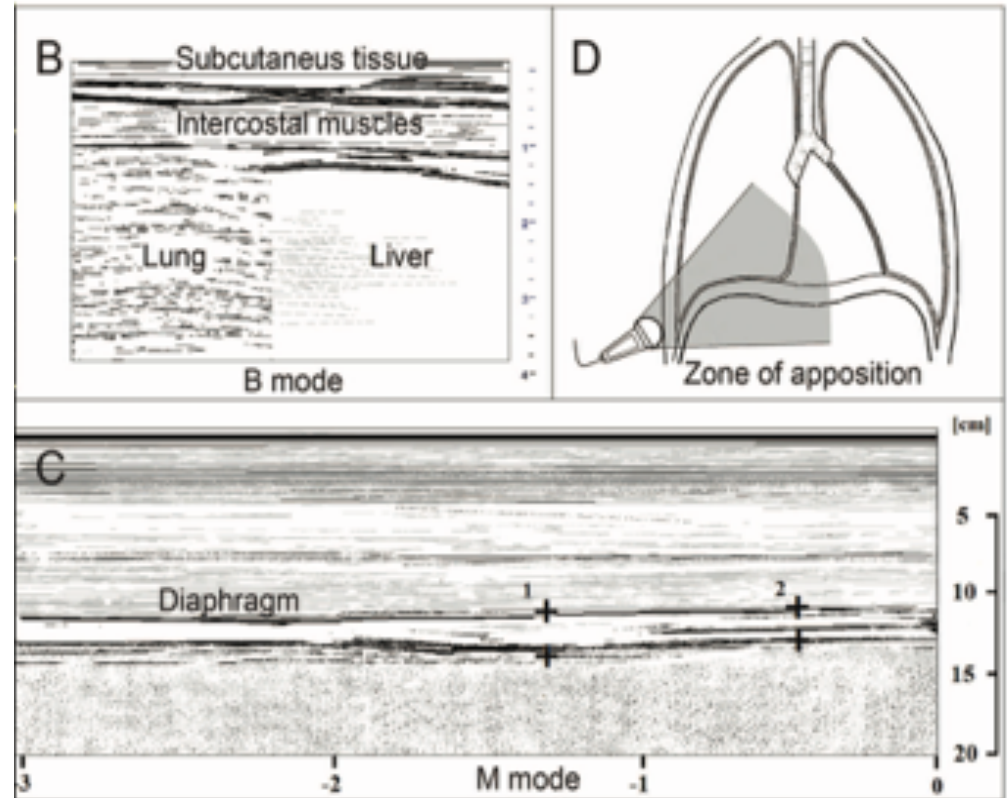
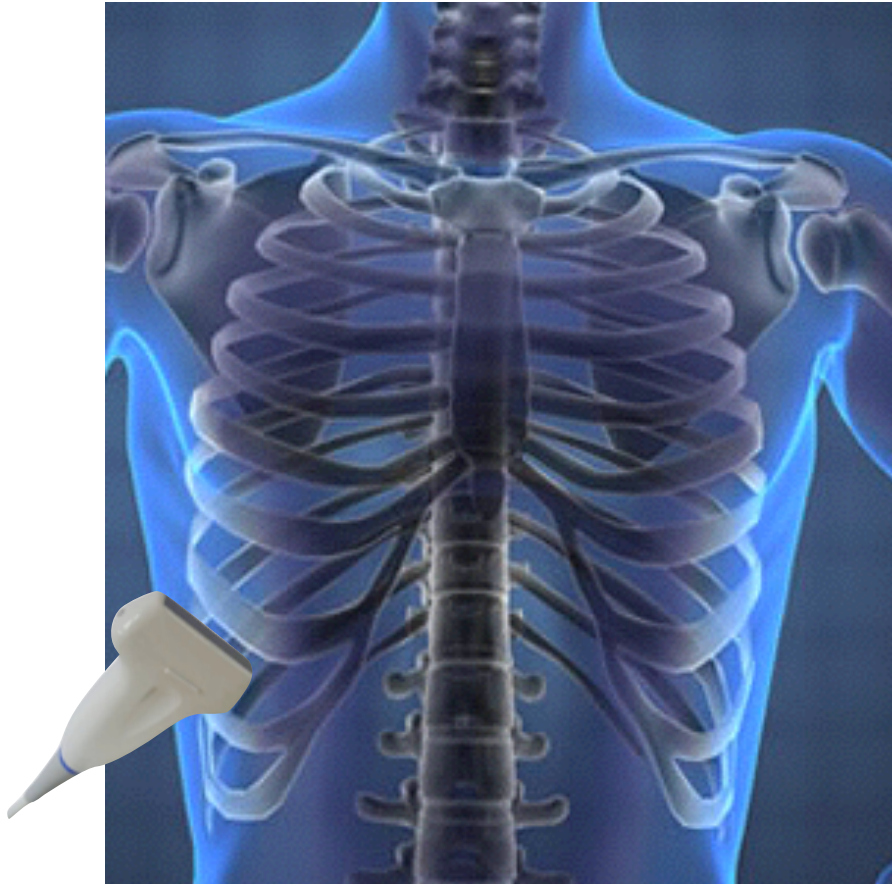
# Inspiratory excursion <10mm or paradoxical movement

Table 2. Weaning variables of the study patients with and without DD

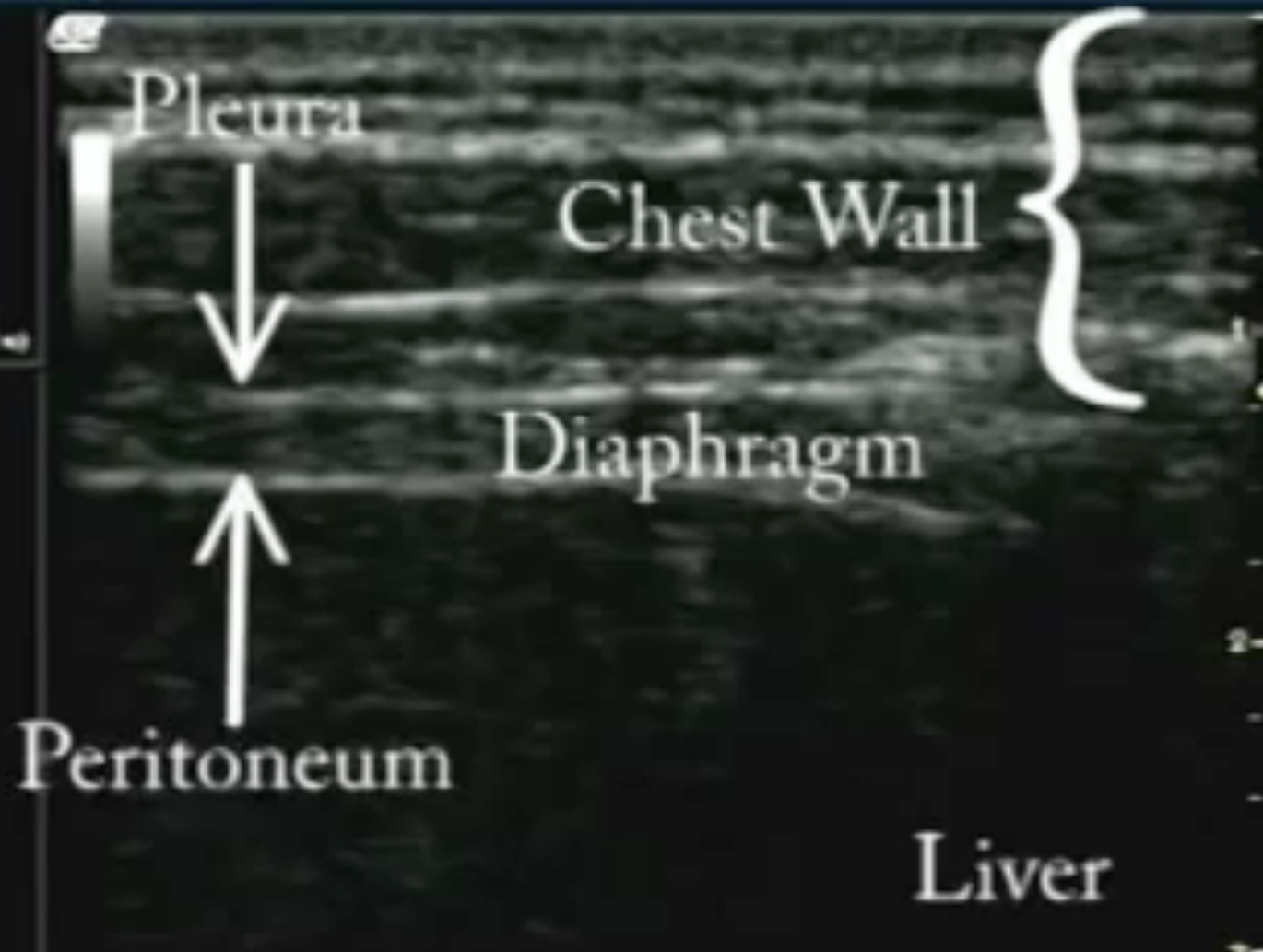
Variables	DD Group	Non-DD Group	<i>p</i>
Total ventilation time, hrs (IQR)	576 (374–850)	203 (109–408)	<.01
Weaning time, hrs (IQR)	401 (226–612)	90 (24–309)	<.01
Time to the spontaneous breathing trial, day (IQR)	4 (2.5–7.5)	4 (3.0–6.0)	.55
Primary weaning failure, no. (%)	20/24 (83)	34/58 (59)	<.01
Secondary weaning failure, no. (%)	10/20 (50)	10/46 (22)	.01
Died before weaning, no. (%)	4/24 (17)	12/58 (21)	.79

DD, diaphragmatic dysfunction; IQR, interquartile range.

# Thickness of diaphragm (Tdi) Thickening fraction (TF)



- Linear probe
- Anteroaxillary line
- 8~10th intercostal space



R	
Freq	8.0 MHz
Ch	54
E/A	0.3
Map	F/T
D	3.0 cm
DR	81
FR	41 Hz
AD	100 %

75dB (S.A.T.L.R. 4)

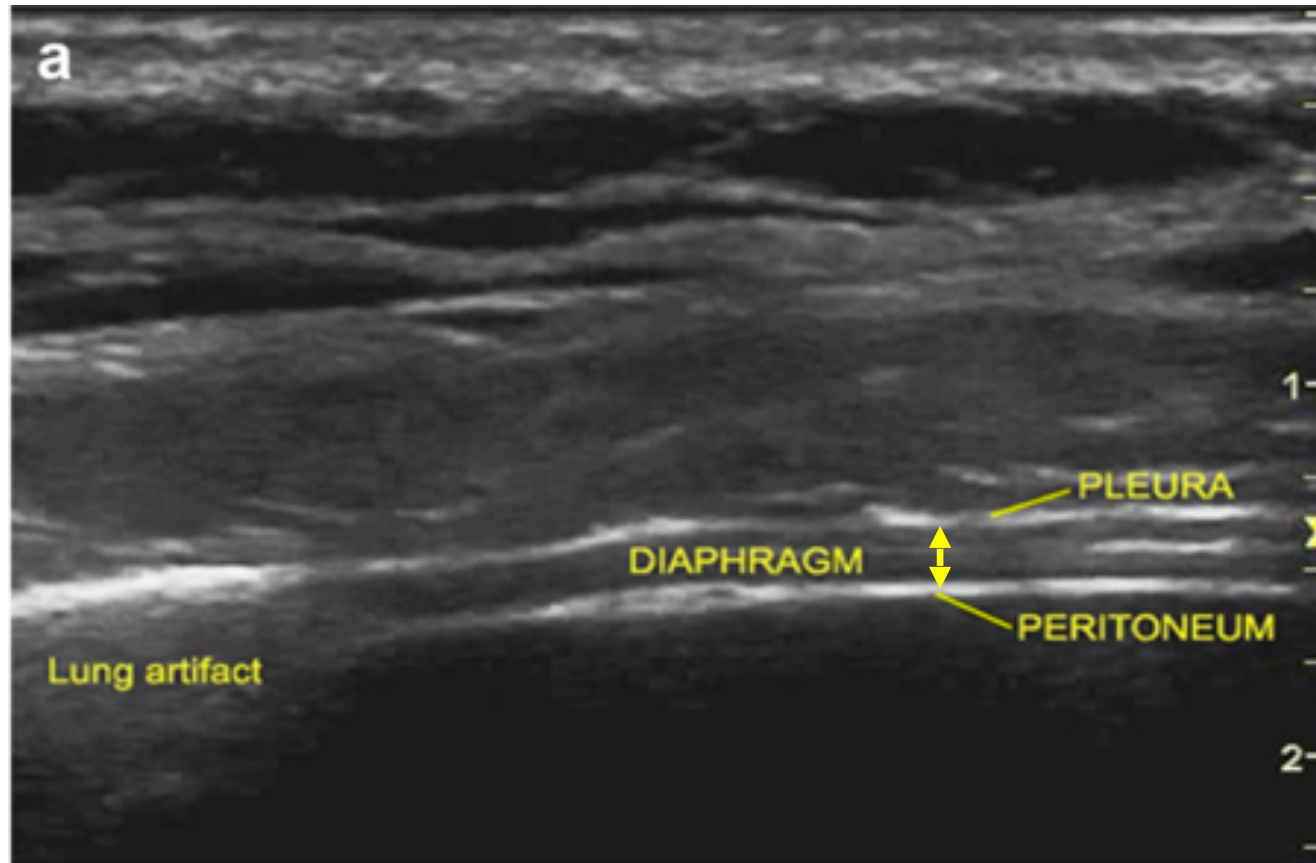
Menu  
Default  
Active

Mode: B mode

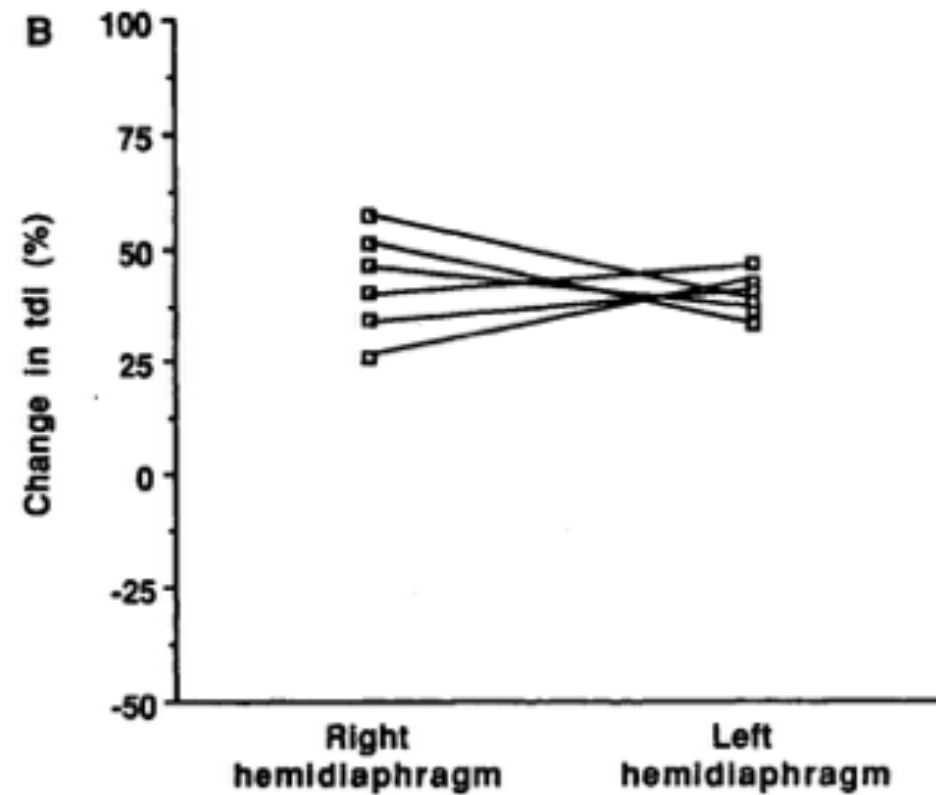
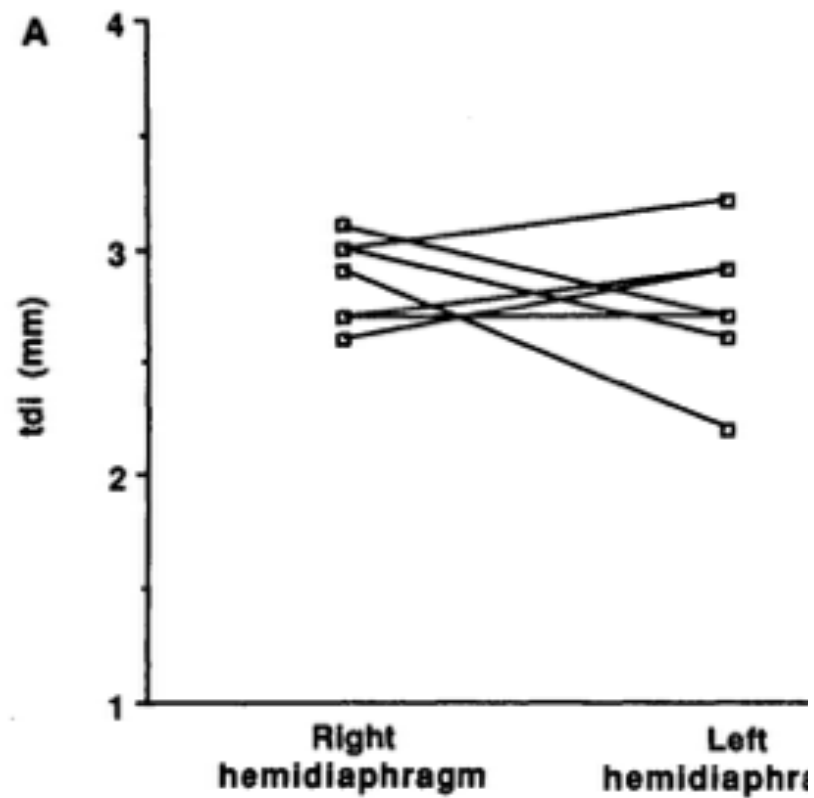
Frequency	Gain Map	Dynamic Range	Image Refresh	Focus Position
Colorize	Edge Enhance	Up/down Invert	Focus Number	

CAPS

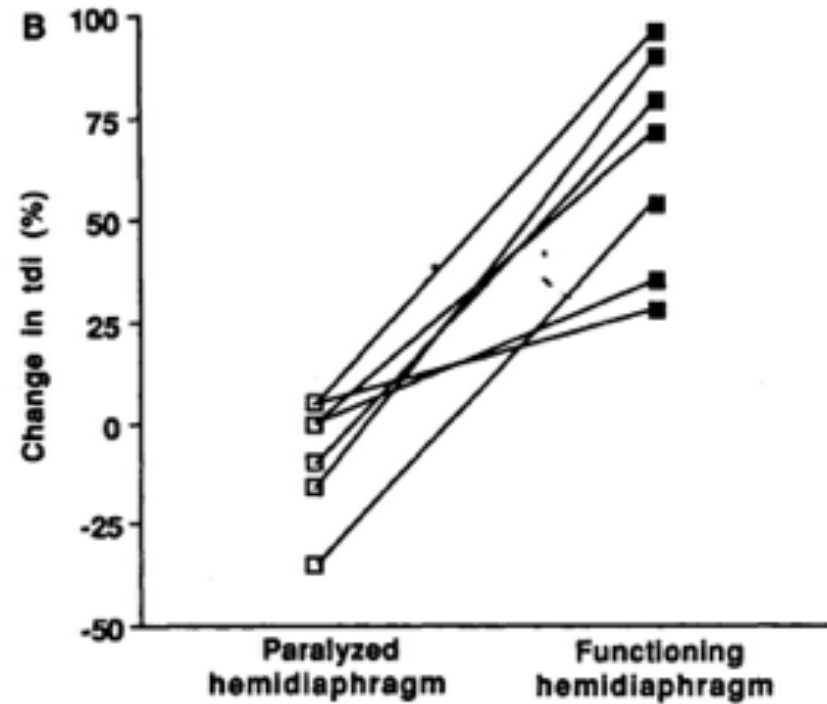
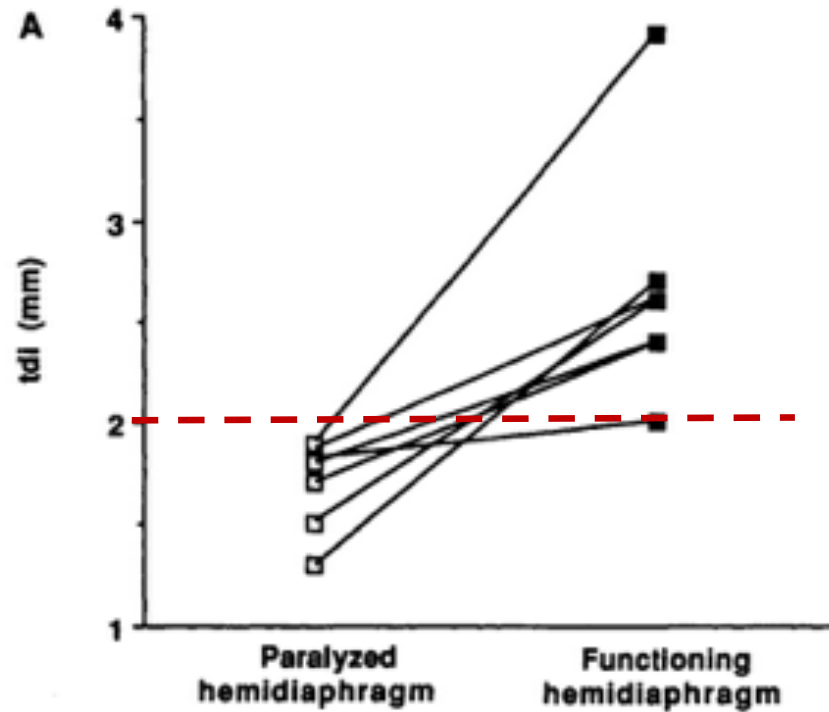
## B mode- Tdi



- Tdi= thickness of the hypoechoic structure



No difference between Rt and Lt hemidiaphragm



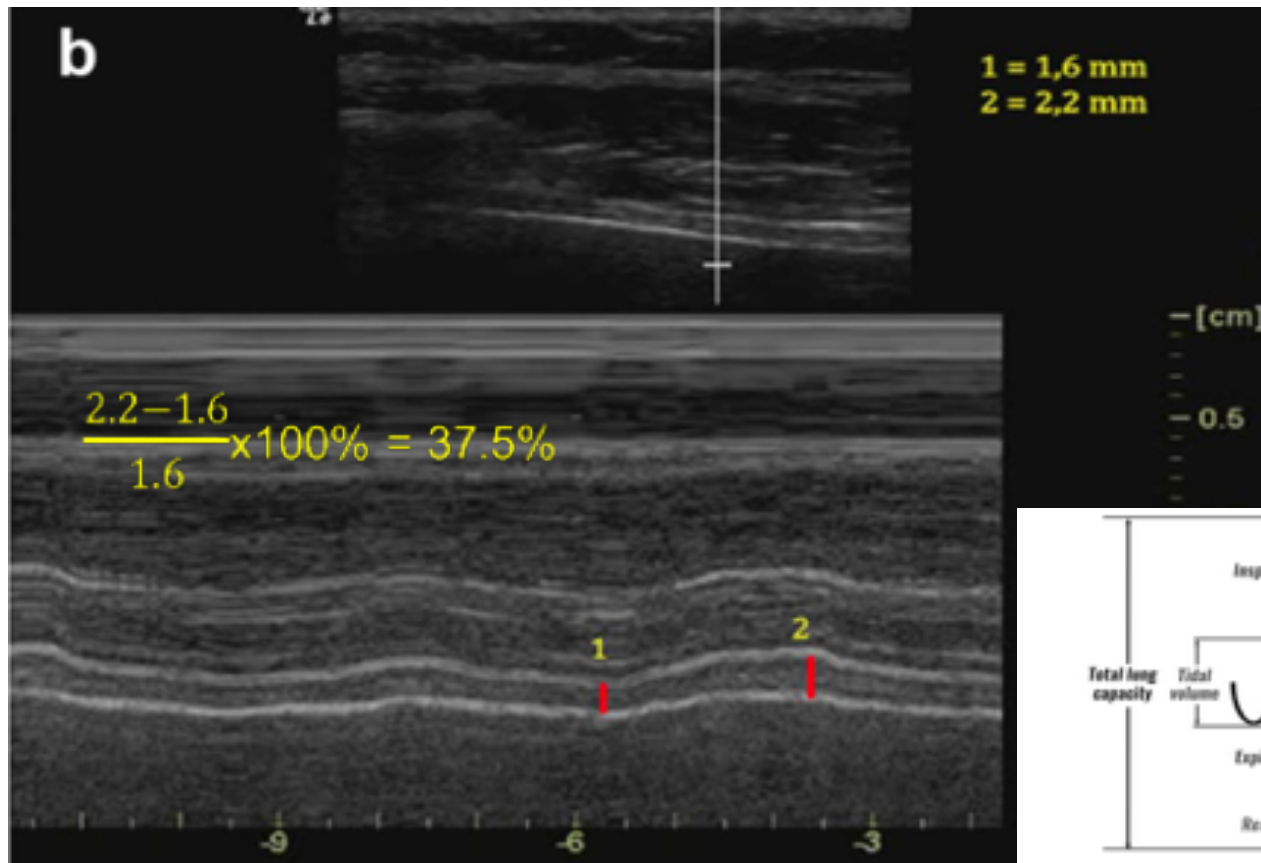
## Paralyzed diaphragm

- < 2 mm
- Significantly thinner than normal diaphragm

False positive: small body size

False negative: acute paralysis

# M mode- TF



- Thickening fraction (TF) =  $\Delta Tdi = \frac{(Tdi_{TLC} - Tdi_{FRC})}{Tdi_{FRC}} \times 100\%$

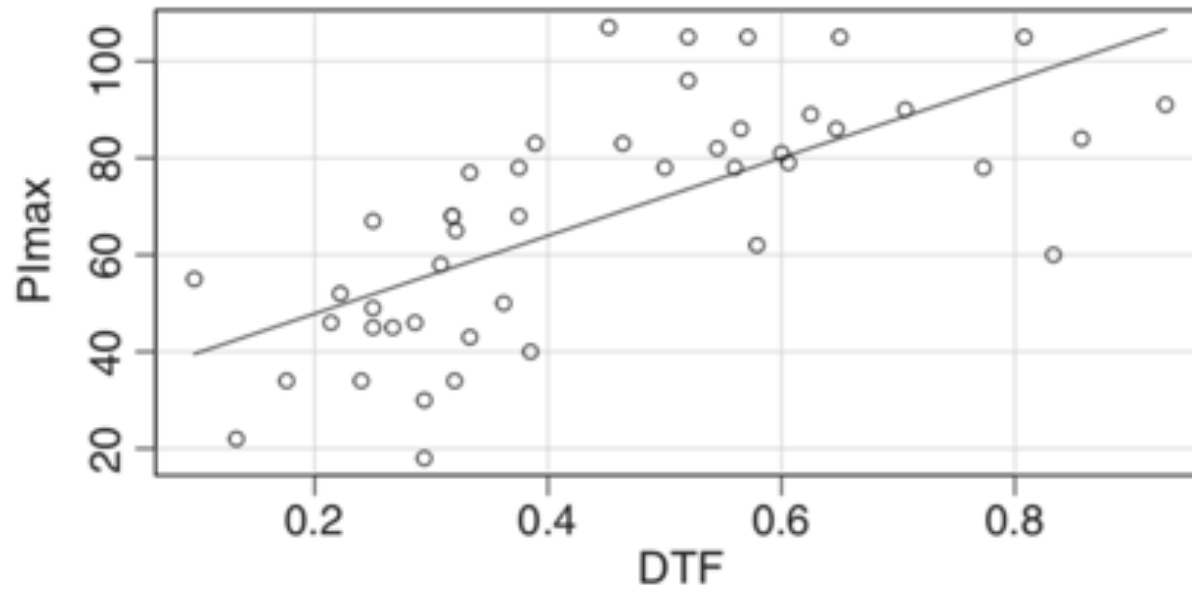
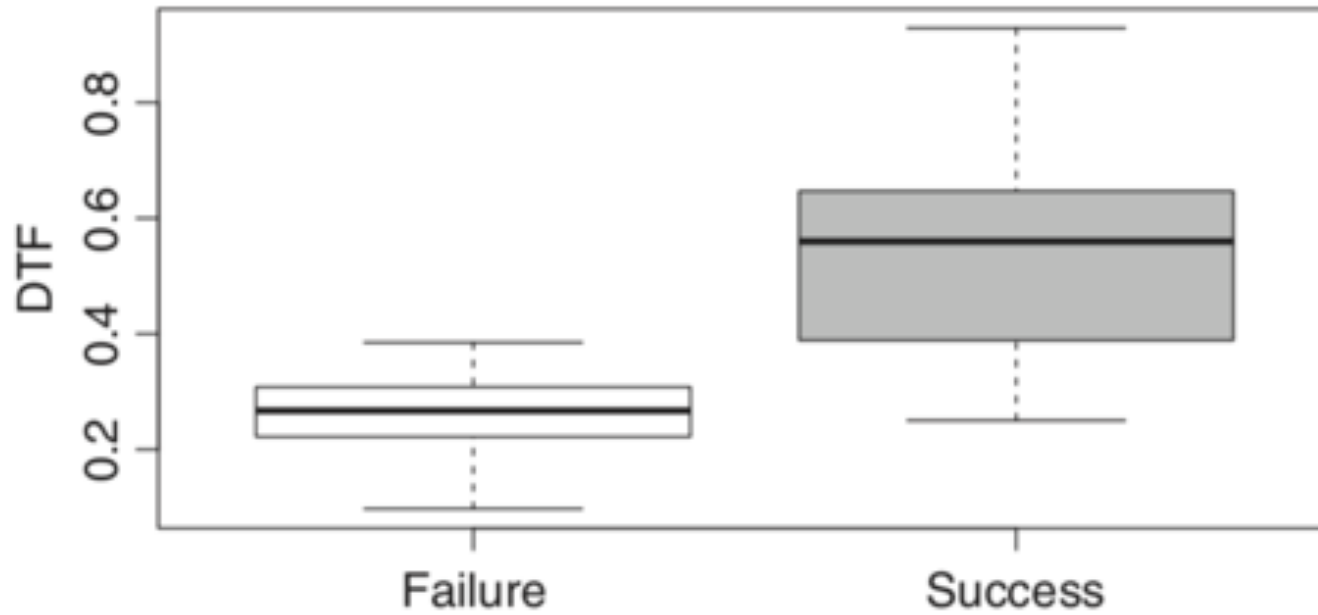


# Diaphragm ultrasound as a new index of discontinuation from mechanical ventilation

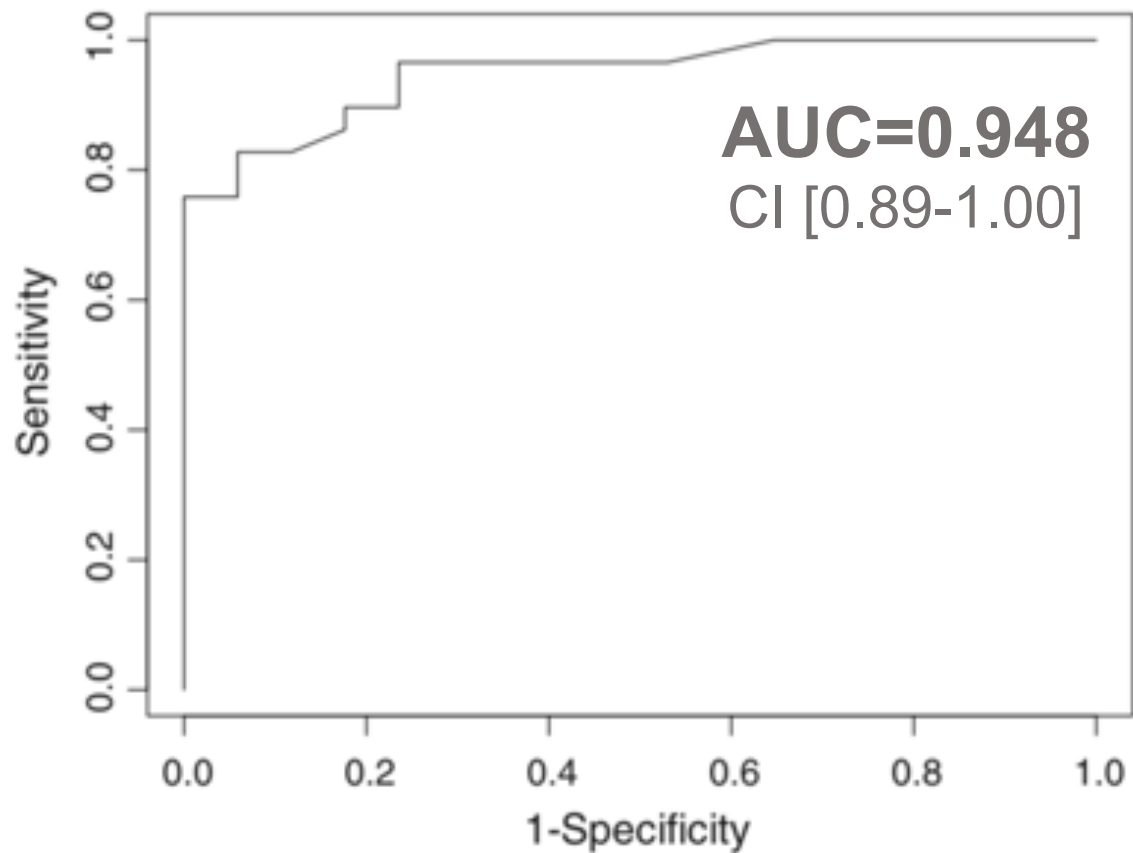
Giovanni Ferrari<sup>1\*</sup>, Giovanna De Filippi<sup>1</sup>, Fabrizio Elia<sup>1</sup>, Francesco Panero<sup>1</sup>, Giovanni Volpicelli<sup>2</sup> and Franco Aprà<sup>1</sup>

**Table 1 Patient characteristics**

	All (n = 46)	Success (n = 29)	Failure (n = 17)	p value
Age	64.6 (12.1)	64.3 (13.7)	65.8 (10)	0.72
Male/female	34/12			
BMI	23 [22 to 27]	24 [22 to 27]	23 [20 to 26]	0.66
SAPS II	34 [33 to 39]	33 [29 to 45]	36 [33 to 43]	0.12
$D_{TLC}$	0.34 [0.26 to 0.44]	0.38 [0.29 to 0.45]	0.30 [0.20 to 0.40]	0.08
$D_{RV}$	0.24 [0.17 to 0.30]	0.25 [0.19 to 0.28]	0.24 [0.17 to 0.30]	0.81
<b>DTF</b>	<b>0.38 [0.29 to 0.44]</b>	<b>0.56 [0.38 to 0.64]</b>	<b>0.26 [0.22 to 0.30]</b>	<b>&lt;0.0001</b>
RSBI	85 [65 to 112]	70 [57 to 83]	120 [110 to 148]	<0.0001
RR	28 [18 to 58]	27 [18 to 32]	31 [24 to 58]	0.001
P <sub>I</sub> max	67.5 (23.9)	82.9 (13.6)	41.2 (11.2)	<0.0001
V <sub>te</sub>	340 [290 to 380]	360 [260 to 700]	280 [210 to 500]	0.007
HDU length of stay	15 [11 to 23]	15 [11 to 19]	22 [15 to 28]	0.02
Duration of ventilatory treatment	28 [22 to 37]	26 [19 to 30]	37 [28 to 45]	0.011
Mortality	3	1	2	

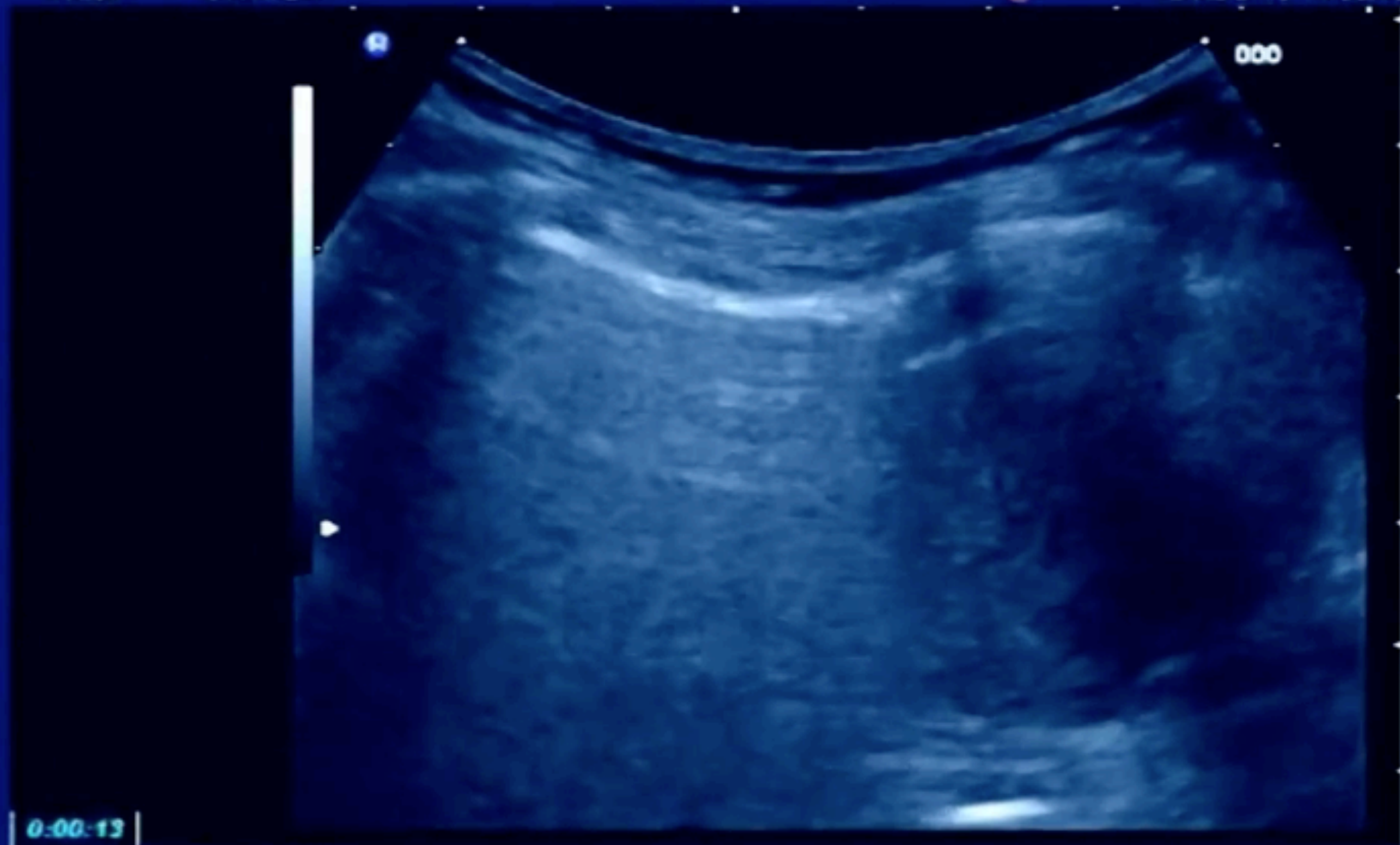


*Rho=0.75,  
p<0.001*



## Cut-off value: 36%

- Sen=0.82
- Spe=0.88
- PPV=0.92
- NPV=0.74



0:00:13

BG:18 80I+2J4/2J+  
C715 dTHI-C Contrast-SonoVue 85mm

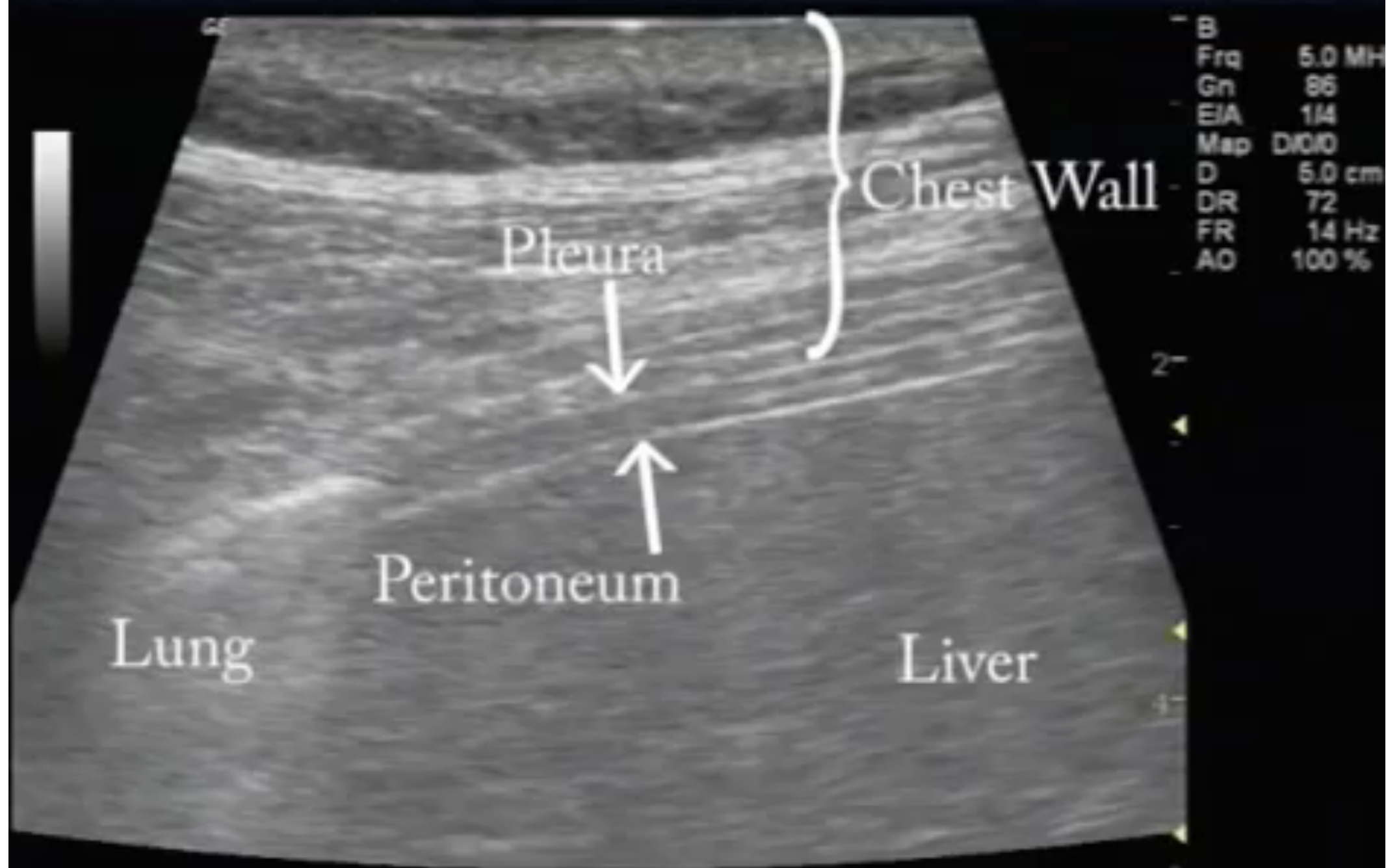
Contrast Alt. mode T. Start MTI L. Focus Focus

**Table 2—Comparisons of the Traditional Weaning Parameters and MD Between Groups\***

Variables	SG	FG	P Value
P <sub>I</sub> max, cm H <sub>2</sub> O†	- 46.3 ± 10.6	- 35.0 ± 15.3	0.002
V <sub>T</sub> spon, mL†	382 ± 119	286 ± 111	0.004
RSBI, L/min × L†	73 ± 30	136 ± 43	< 0.001
MD, cm†	1.45 ± 0.48	0.84 ± 0.39	< 0.001

**Table 3—Sensitivity and Specificity of Traditional Weaning Parameters and MD for Predicting Successful Extubation**

Tests	Sensitivity, %	Specificity, %	Area*
P <sub>I</sub> max ≤ - 20 cm H <sub>2</sub> O	93.1	50.1	0.74
V <sub>T</sub> spon ≥ 5 mL/kg body weight	71.9	65.2	0.73
RSBI ≤ 105	81.3	56.5	0.81
MD ≥ 1.1 cm	84.4	82.6	0.84



# US of Diaphragm

Easy and quick

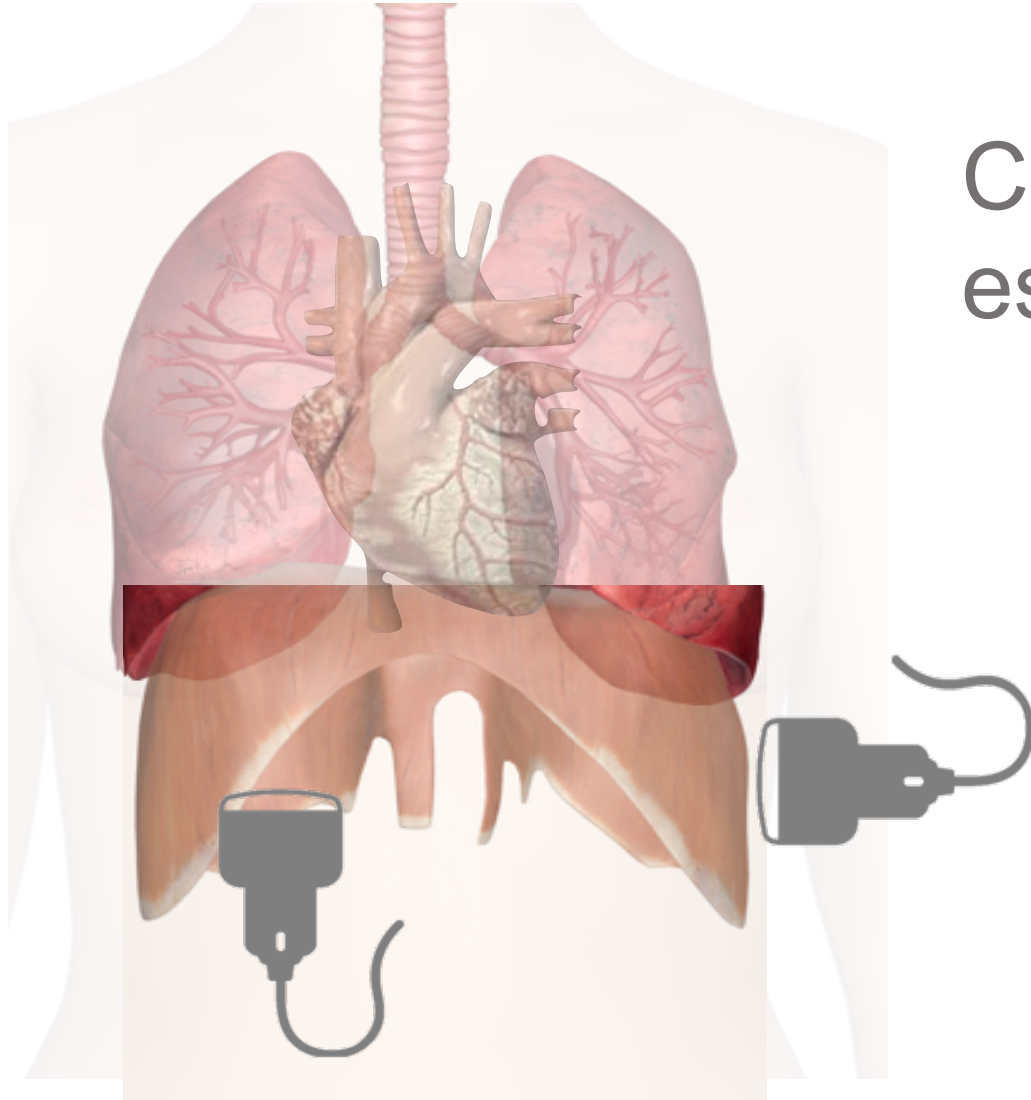
Cut value is not well established

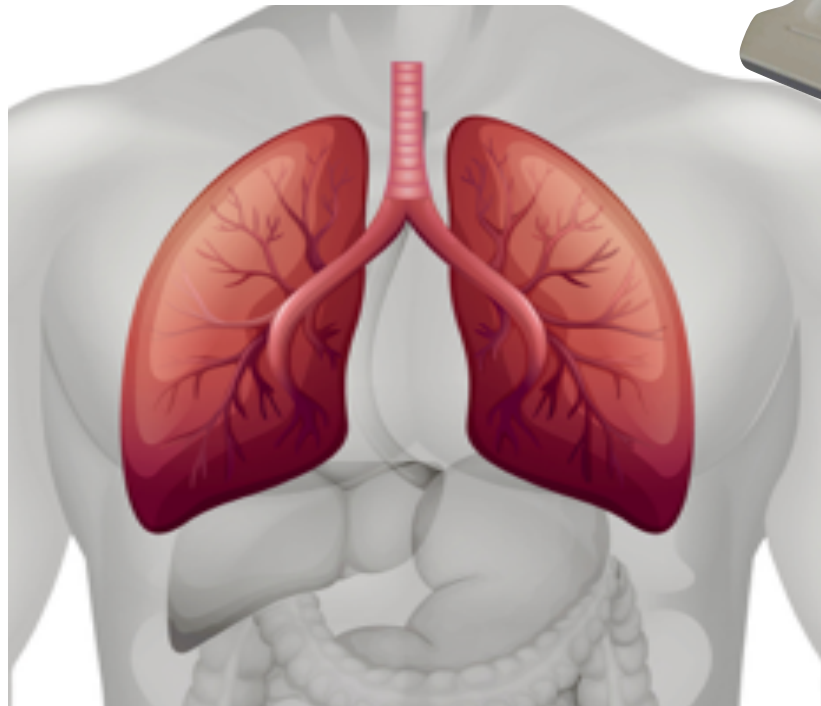
Thickness  $< 2\text{mm}$

Thickness fraction  $< 30\sim 36\%$

Inspiration excursion  $< 10\text{mm}$

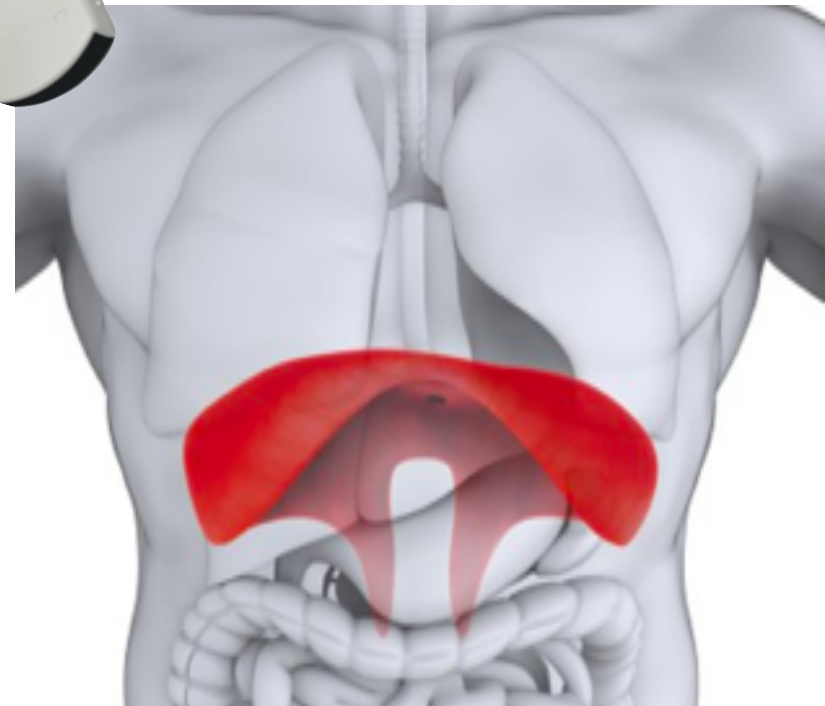
Diaphragm movement  $< 1.1\text{cm}$





### Lung US re-aeration score

+ 8 or more = +600ml  
+ 4 or less = +75~450 ml  
( $Rho=0.63$ ;  $P<0.05$ )



### Weaning threshold

TF  $\geq 30\sim 36\%$   
Insp excursion  $\geq 1.1$  cm



ORIGINAL ARTICLE

Open Access

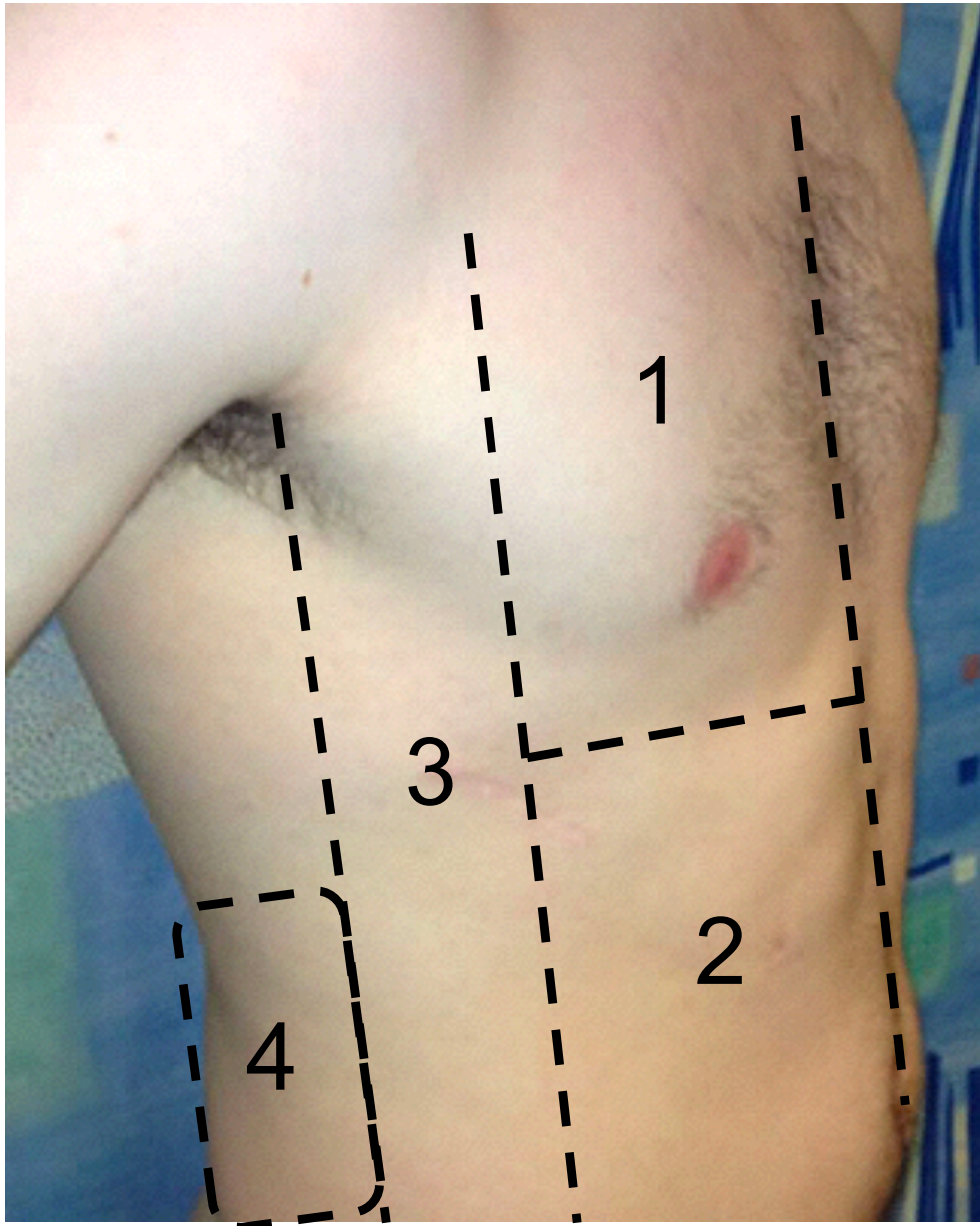


# Lung and diaphragm ultrasound as predictors of success in weaning from mechanical ventilation

Eva Tenza-Lozano<sup>1\*</sup> , Ana Llamas-Alvarez<sup>1</sup>, Enrique Jaimez-Navarro<sup>1</sup> and Javier Fernández-Sánchez<sup>2</sup>

Cross-sectional concordance study  
Prospective cohort study

# Lung examination- Modified LUS (LUSm)

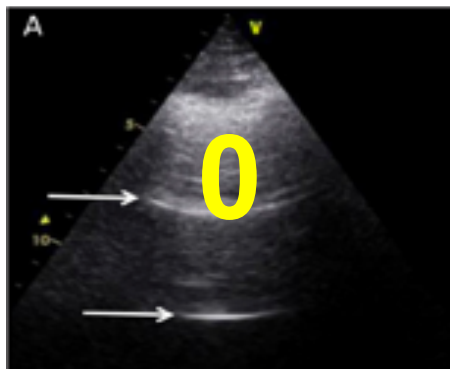


4 area on each site

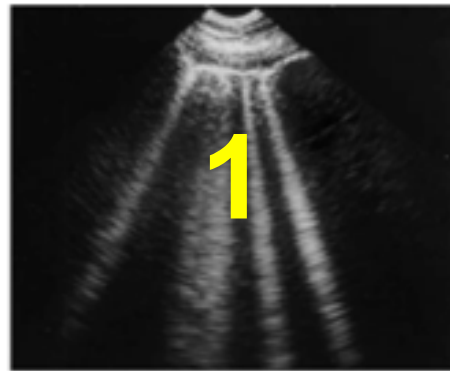
- anterior–superior,
- anterior-inferior,
- lateral
- postero-basal

Avoid moving critical pt

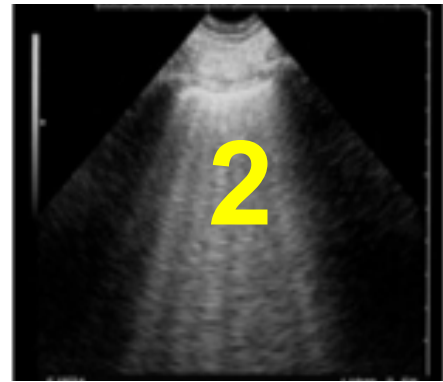
- prevent complications
- facilitating examination process



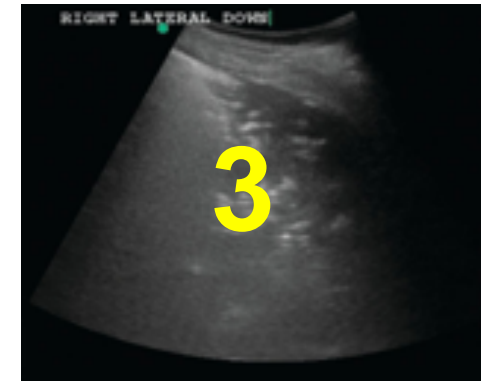
Normal



Moderate loss of aeration

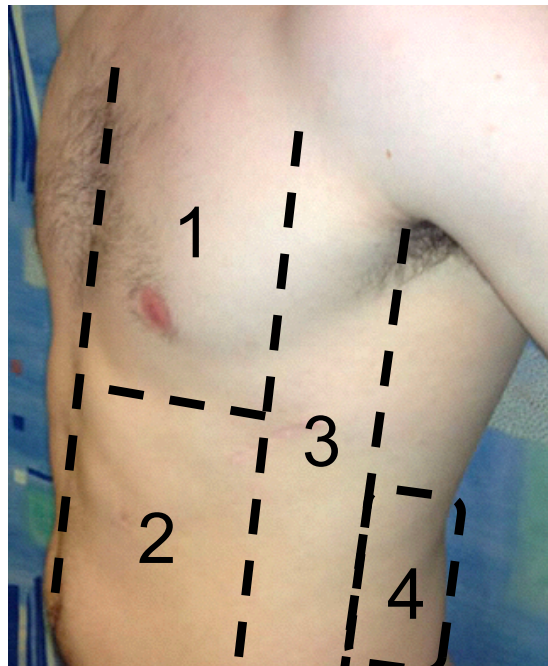
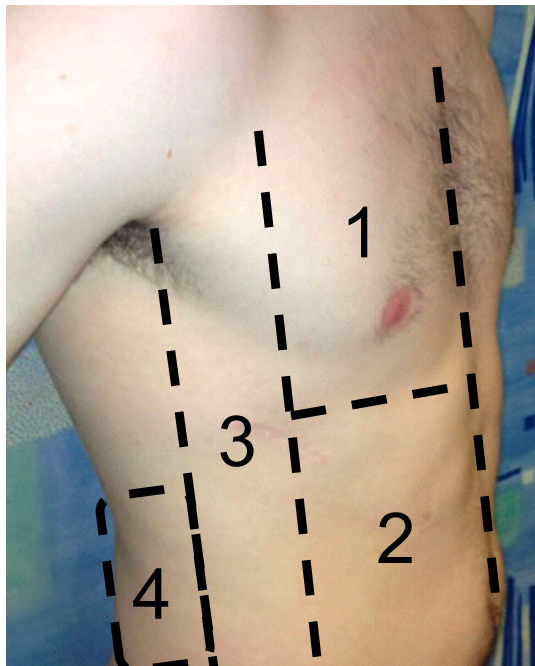


Severe loss of aeration



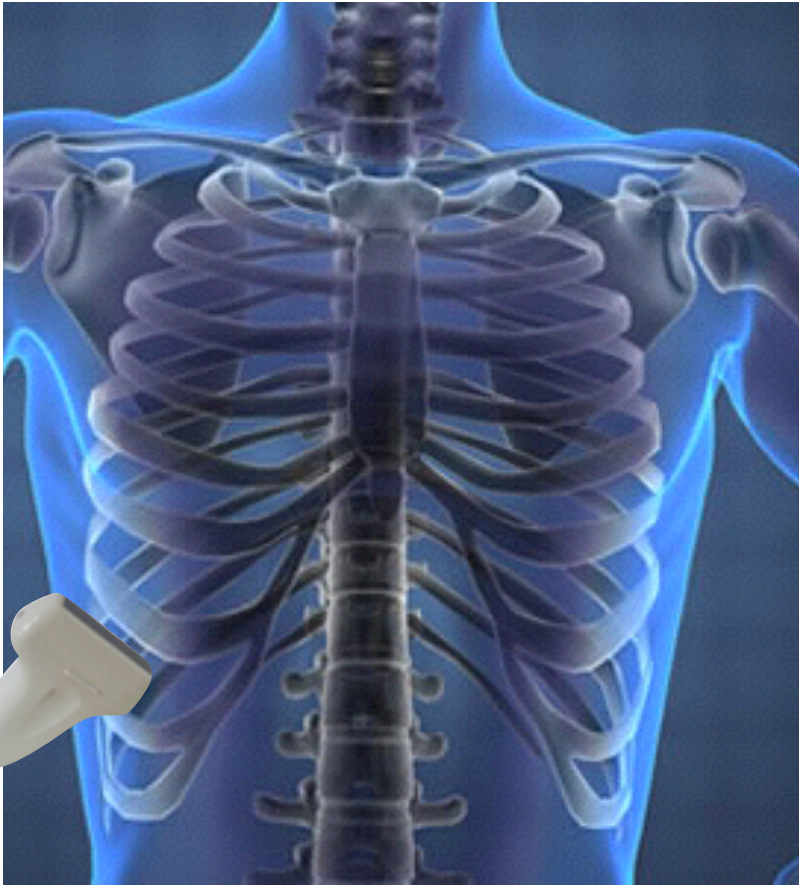
Consolidation

👍 **N**      **B1**      **B2**      **C** 👎

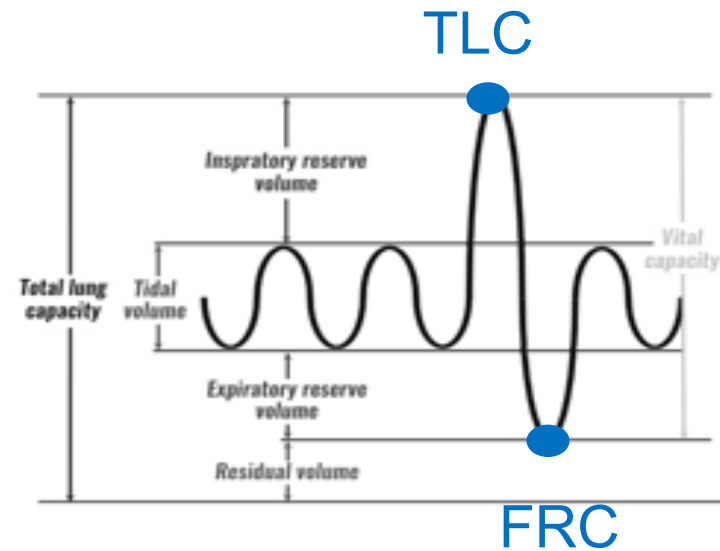


- Total 8 region
- Score: 0~24

# Diaphragm examination- Thickening index (TI)



$$\bullet \text{ TI} = \frac{(\text{Tdi TLC} - \text{Tdi FRC})}{\text{Tdi TLC}} \times 100\%$$



- Linear probe
- Midaxillary line
- 8~10th intercostal space

**Table 1 Characteristics of patients included in the study**

Variables	All patients (69)	SW (44)	FW (25)	P value
Sex (men) <sup>a</sup>	43 (62.3)	26 (63.4)	15 (62.5)	0.8
Age (years) <sup>b</sup>	66 (53, 78)	65 (53, 78)	69 (64, 78)	0.37
Time on MV (days) <sup>b</sup>	4 (3, 7)	4 (2, 6)	5 (3, 9)	0.04
LUSm <sup>b</sup>	6 (4, 8)	5 (3, 7)	8 (7, 11)	0.0001
TI (%) <sup>b</sup>	36 (27, 41)	38 (31, 45)	27 (20, 40)	0.003
APACHE II on SBT day <sup>b</sup>	4 (2, 6)	4 (2, 6)	5 (3, 9)	0.07
VE (L/min) <sup>b</sup>	8.6 (7.5, 10)	8.25 (7.3, 9.8)	9 (8.1, 11.6)	0.13
Compliance (mL/cm H <sub>2</sub> O) <sup>b</sup>	56 (41, 67)	55.5 (43, 69)	59 (40.5, 67)	0.86
Pl <sub>Max</sub> (cm H <sub>2</sub> O) <sup>b</sup>	-25 (-23, -25)	-25 (-25, -18)	-25 (-26, -24)	0.28
P0.1 (cm H <sub>2</sub> O) <sup>b</sup>	1 (1, 3)	1 (1, 3)	1.5 (1, 2.5)	0.47
RSBI (breaths/min/L) <sup>b</sup>	35 (20, 50)	31 (20, 43)	37 (30, 54)	0.16
RR (breaths/min) <sup>b</sup>	17 (15, 20)	17 (14, 19)	19 (16, 22)	0.09
Tidal volume (ml) <sup>b</sup>	400 (450, 585)	508 (452, 572)	500 (440, 600)	0.71
FiO <sub>2</sub> (%) <sup>b</sup>	30 (28, 35)	30 (28, 35)	30 (28, 35)	0.83
SpO <sub>2</sub> (%) <sup>b</sup>	98 (97, 100)	99 (97, 100)	97 (96, 99)	0.027
PaCO <sub>2</sub> (mm Hg) <sup>b</sup>	40 (36, 46)	41 (36, 45.6)	39.6 (37, 45)	0.63
PaO <sub>2</sub> , (mm Hg) <sup>b</sup>	93 (79, 115)	96.5 (83, 117)	92 (74, 115)	0.61
pH <sup>b</sup>	7.42 (7.32, 7.47)	7.4 (7.3, 7.5)	7.4 (7.4, 7.4)	0.93
Lactate (mmol/L) <sup>b</sup>	1.2 (1, 1.7)	1.2 (1, 1.5)	1.3 (1.1, 2)	0.2
ICU mortality <sup>a</sup>	7 (14)	1 (2.3)	6 (24)	0.005
Hospital mortality <sup>a</sup>	11 (16)	3 (6.8)	8 (32)	0.003
ICU stay (days) <sup>b</sup>	11 (7, 19)	8 (6, 15)	18 (11, 21)	0.002
Hospital stay (days) <sup>b</sup>	19 (14, 30)	17 (13.5, 31)	23 (17, 30)	0.08

**Table 3 Predictive value of LUSm and TI for successful extubation**

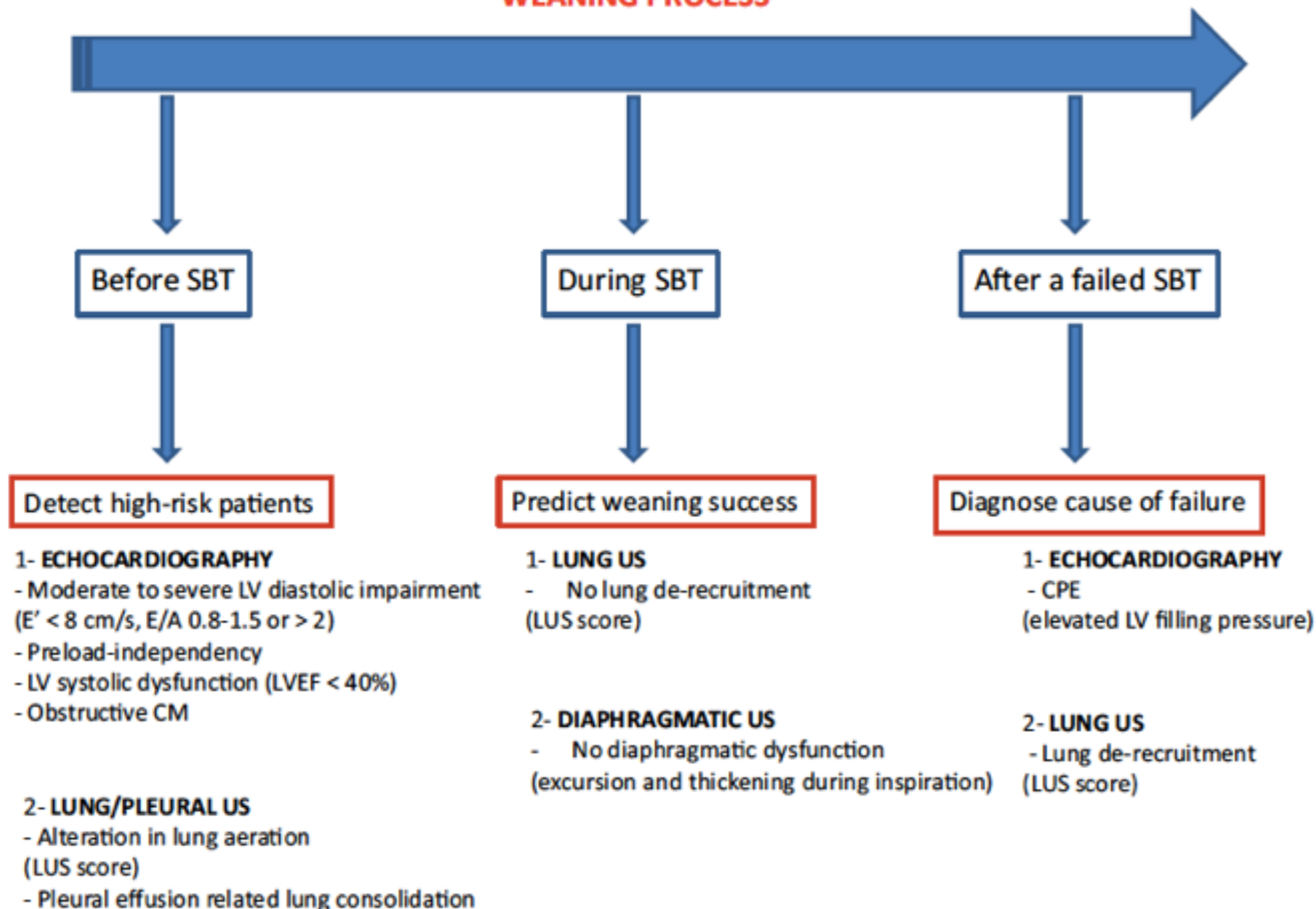
Variable	AUC	Sensitivity	Specificity	LR+	LR-	Cut-off point (%)
LUSm	0.78	0.76	0.72	2.74	0.33	7
TI	0.76	0.93	0.58	2.26	0.12	24
LUSm+TI	0.83	0.86	0.56	1.97	0.24	



## Inter-operator agreement (Kappa value)

- LUSm: 0.95 *CI* [0.92,0.98]
- TI: 0.78 *CI* [0.65,0.87]

## WEANING PROCESS





**US of heart, lung and diaphragm is a promising method for weaning evaluation**

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