Role of diaphragm and airway ultrasound in ICU

Karthik B

Senior resident

7.2.26

Contents

- Background & Rationale

- Diaphragm Ultrasound
    - Technique & Measurements (Excursion, Thickening)
    - Respiratory Effort & Weaning Evidence

- Clinical Applications
    - Extubation Prediction
    - Role in NIV

- Laryngeal Ultrasound
    - Technique & measurement
    - Prediction of Post-extubation Stridor

- Clinical Integration

Introduction

- The diaphragm is the principal muscle of inspiration, contributing to 70% of tidal volume during quiet breathing.

- In critically ill patients, diaphragmatic function is altered by:
  - Mechanical ventilation
  - Sepsis and systemic inflammation
  - Sedation and neuromuscular blockade
  - Critical illness–related neuromyopathy

- Controlled mechanical ventilation leads to rapid diaphragmatic atrophy even within 24–48 hours, leading to reduced force-generating capacity

- Clinical consequences:
  - Prolonged duration of mechanical ventilation
  - Difficult or failed weaning and increased re-intubation
  - Longer ICU stay

Mahmoodpoor et al Anaesth Inten Ther 2022
Llamas Alvarez et al, Chest 2017

How to assess the diaphragm ?

Done in Semi-recumbent position (30–45°)

Should have stable respiratory drive and on minimal or no pressure support

2 approaches:

- **Subcostal approach:** 2–5 MHz curvilinear / phased-array probe

- **Intercostal approach:** 7–12 MHz linear probe

- Use **M-mode** for motion and **B-mode** for thickness

Subcostal Approach for Diaphragm Excursion

Parameters	Procedure
Probe & positioning	• 2–5 MHz probe placed subcostally between the mid-clavicular and anterior axillary line • Probe marker cranial; liver (right) preferred or spleen (left) used as acoustic window
Image acquisition	• Identify diaphragm dome as a hyperechoic line above liver/spleen • Switch to M-mode • Cursor aligned perpendicular to diaphragm motion
Measurement (Diaphragm Excursion – DE)	• Measure vertical displacement from end-expiration to peak inspiration • Perform during: Quiet tidal breathing and Deep breathing/sniff for maximal excursion • Average 3 consistent respiratory cycles

EXCURSION ASSESSMENT
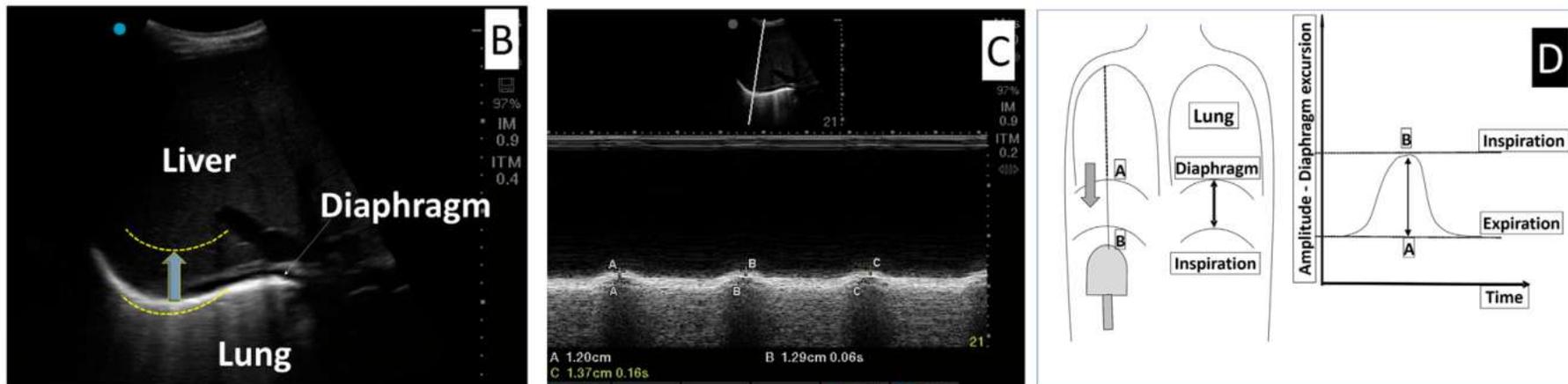
Diaphragm excursion
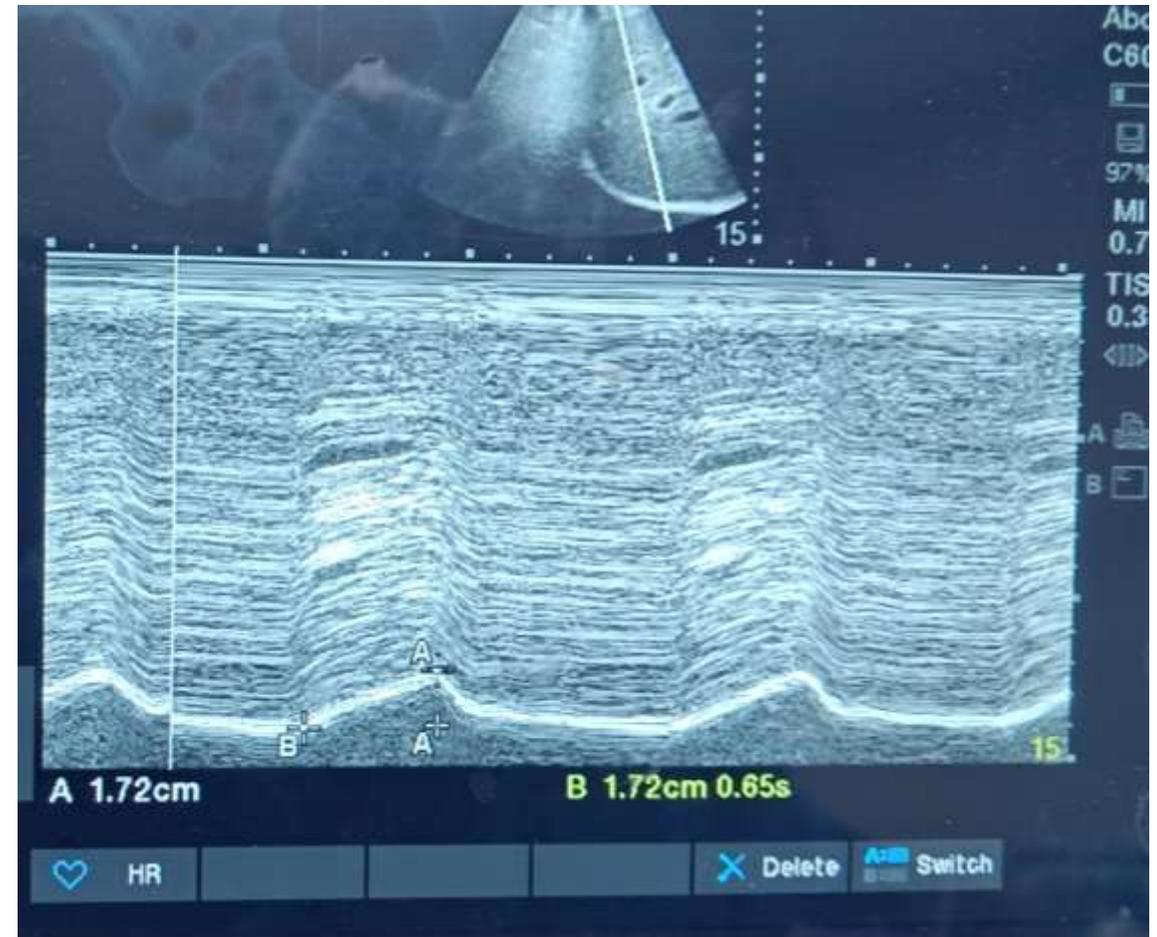
Intercostal approach for thickness & thickening fraction

Parameters	Procedure
Probe & positioning	• 7–12 MHz linear probe • Placed at 8th–10th intercostal space, mid-axillary line • Identify zone of apposition
Image acquisition	In B mode - Diaphragm seen as **three-layer structure**: • Two hyperechoic lines (pleura & peritoneum) • Hypoechoic muscle layer in between
Measurement (Diaphragm thickening fraction)	**DTee:** Thickness at end-expiration **DTpi:** Thickness at end-inspiration **Diaphragm Thickening Fraction (DTF):** (DTpi-DTee)/DTee)*100

INTERCOSTAL VIEW – ZONE OF APPOSITION
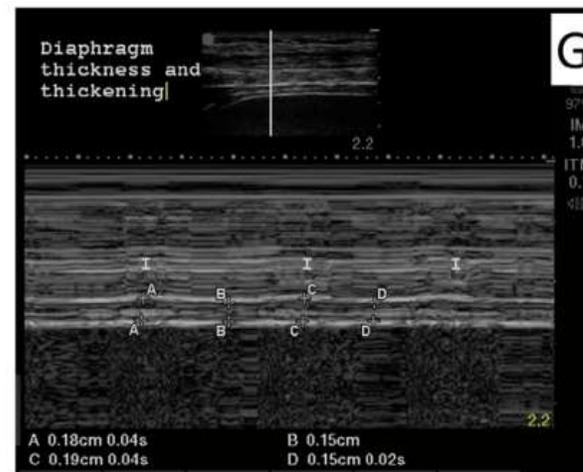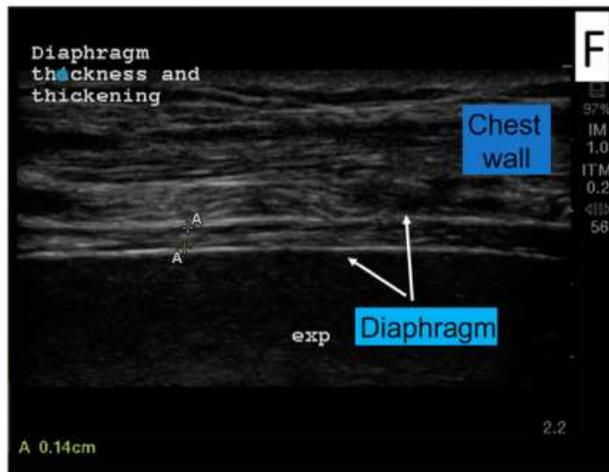
THICKNESS ASSESSMENT

DTF

A 0.24cm

Ellipse   Manual   Delete

A 0.36cm

Ellipse   Manual   Delete
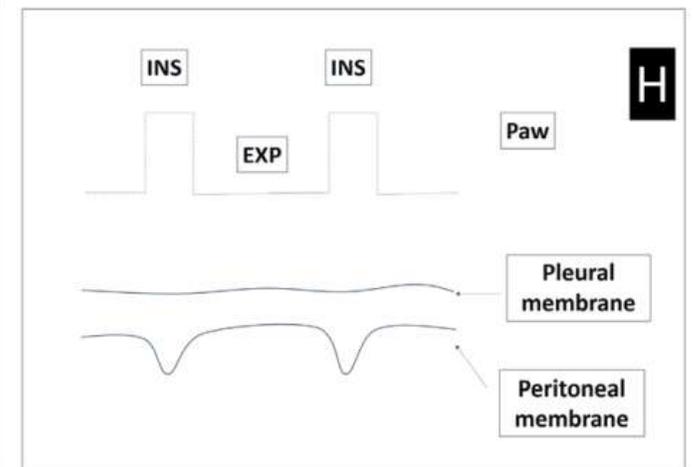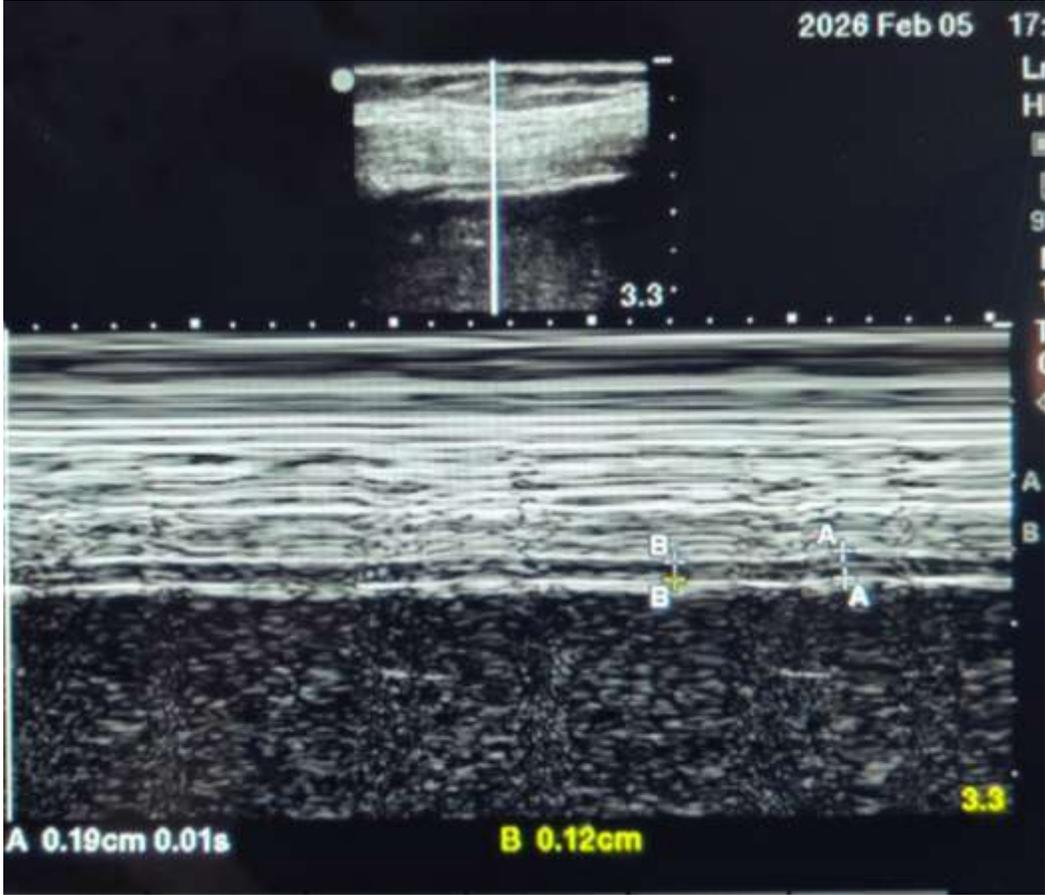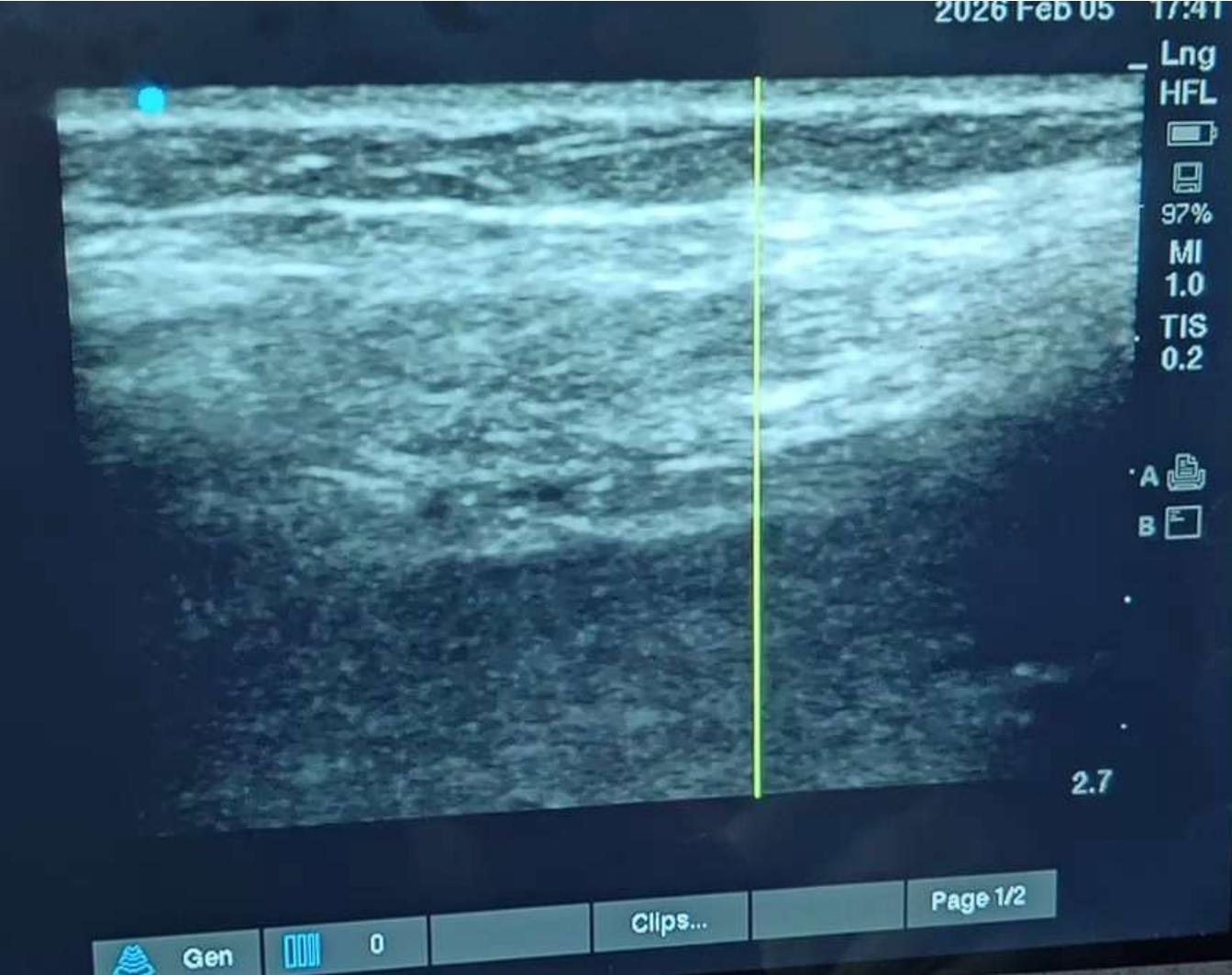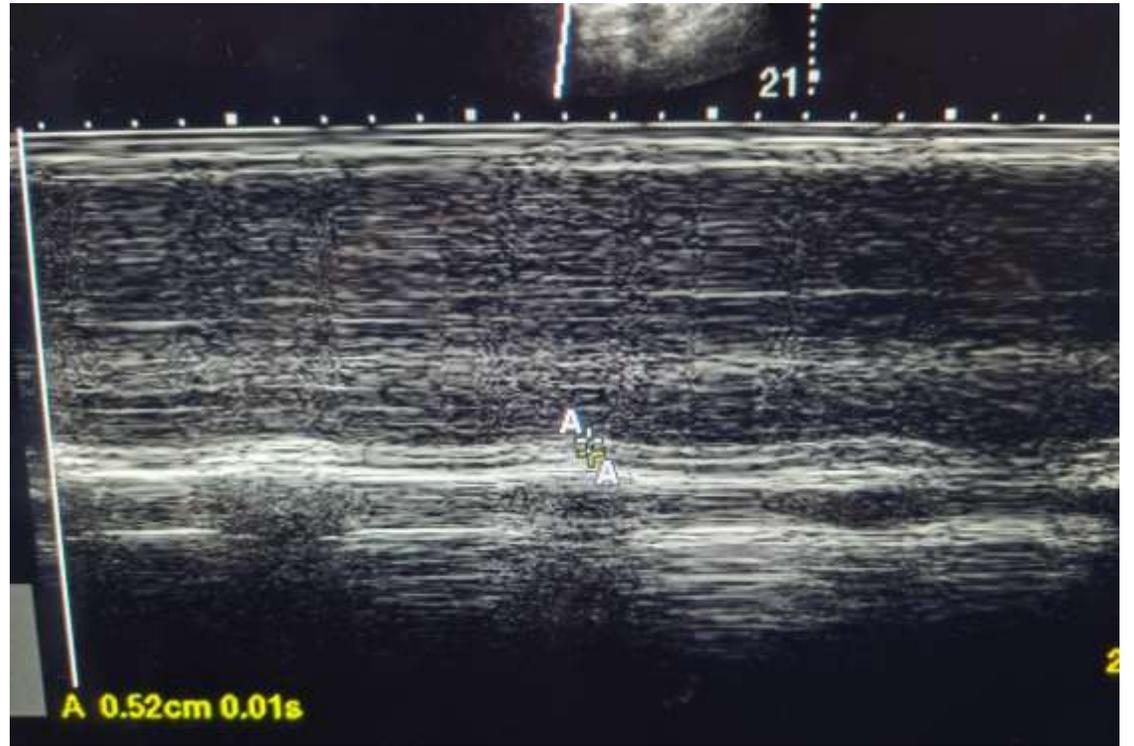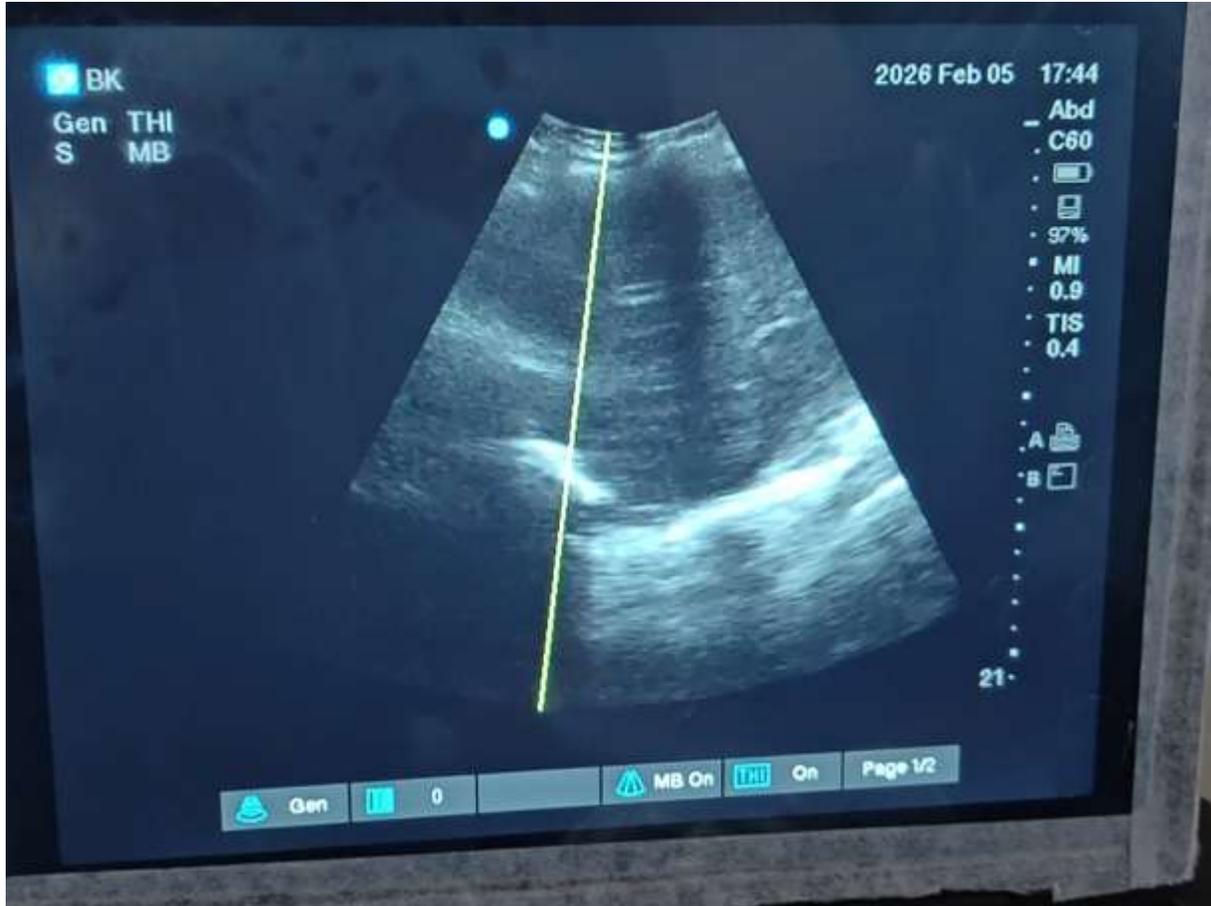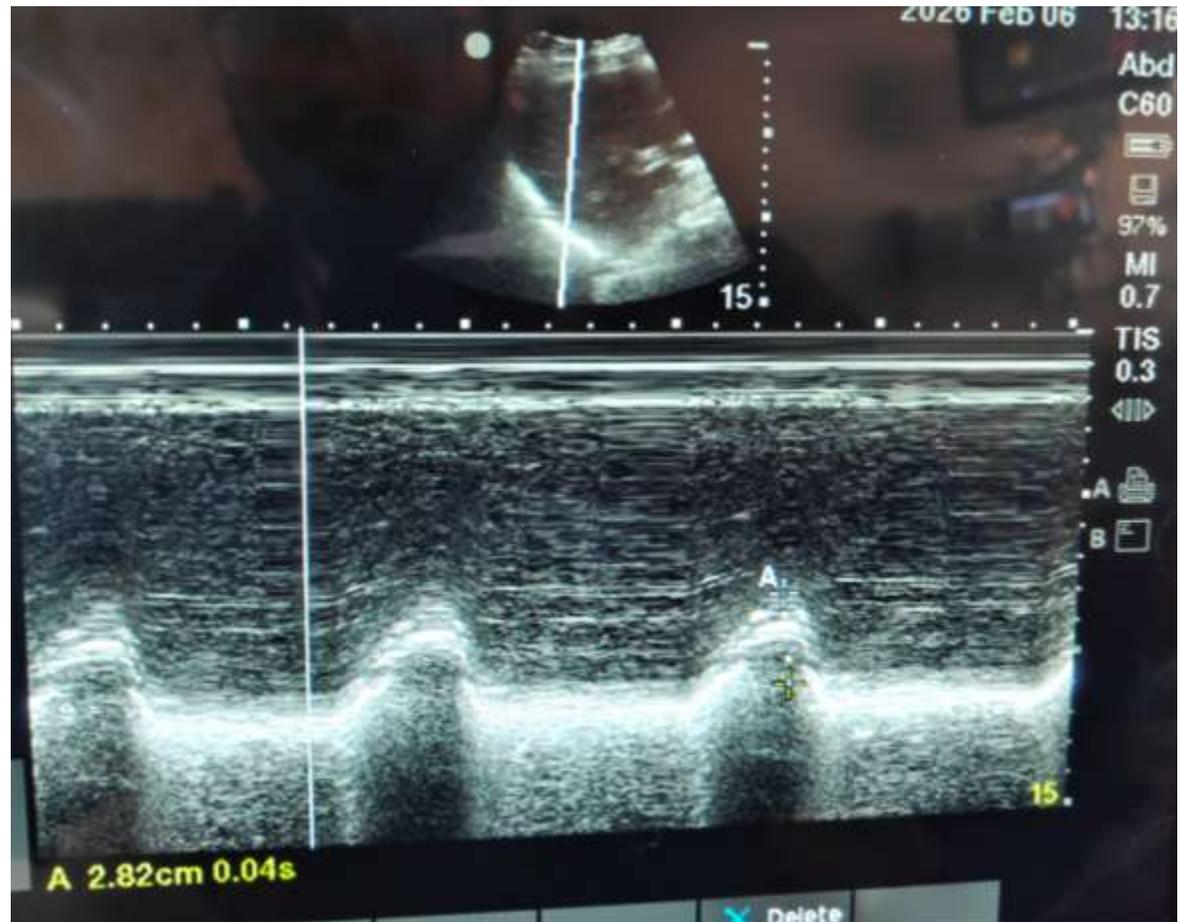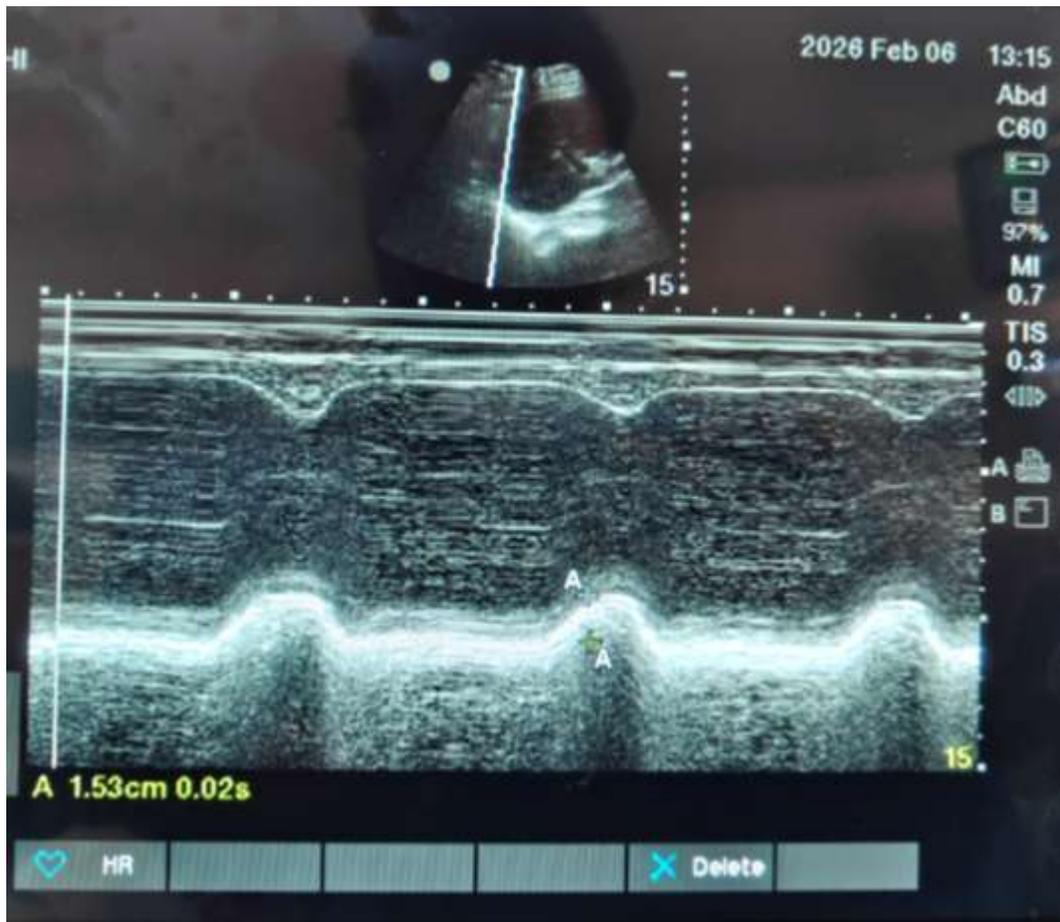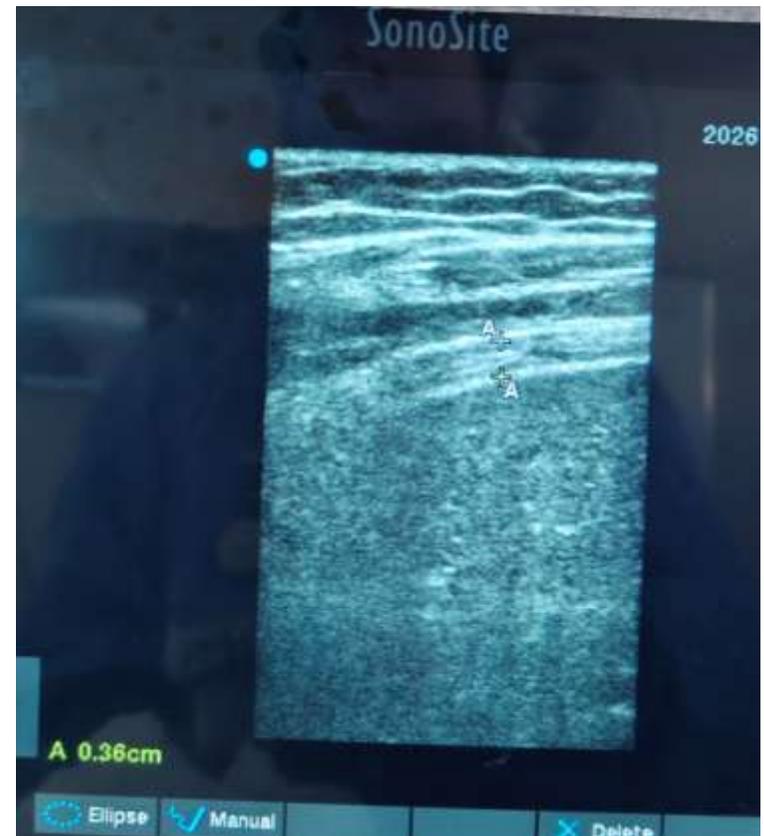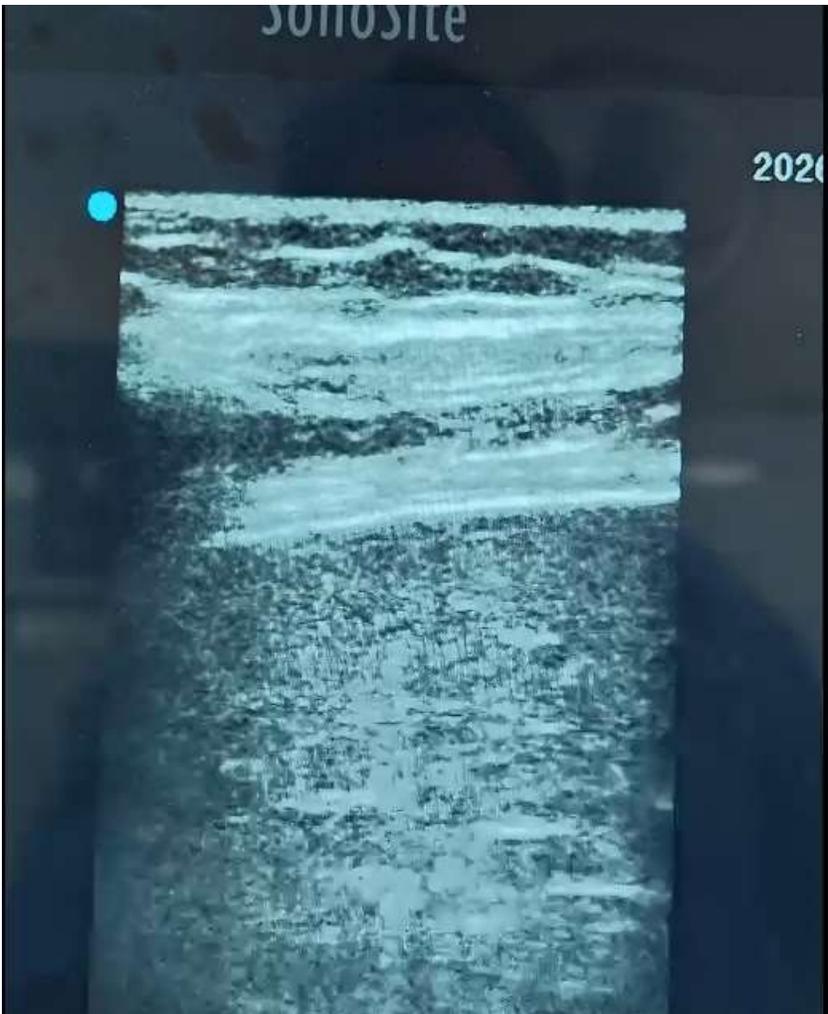
Setting	Parameter	Patient position	Reference values	Abnormal values/values related to outcome
ICU	Thickness (mm)	–	2.4 ± 0.8	
		Semi-recum	2.4 (2.0–2.9)	
		Semi-recum		< 1.7
		Semi-recum	1.9 ± 0.4	
	TFdi	Semi-recum		< 30%
	TFdi(max)	Semi-recum		< 36%
	TFdi	Semi-recum		< 34%
	Tidal excursion (mm)	Supine		< 11 (organ exc.)
		Semi-recum		Right < 14
	Maximal breath (mm)	Semi-recum		Left < 12
		Semi-recum		< 10
				< 25

A study of 191 patients who underwent SBT via T-tube showed a cutoff for extubation failure as **excursion < 10 mm or thickening < 30%.**

Vivier et al 2019
Tuinman et al 2020, Int car med

Diaphragm ultrasound as indicator of respiratory effort during assisted mechanical ventilation

- Prospective physiological single center pilot study
- Included only post-operative patients undergoing PSV ventilation (n=25)
- Diaphragm USG compared with PTPes and PTPdi
- Increasing PS at 0, 5, 15 cm H20 decreases respiratory effort by reduction in TF, PTPes, PTPdi
- Correlation of TF was stronger:
- TF vs PTPes: R = 0.801, p < 0.001
- TF vs PTPdi: R = 0.701, p < 0.001
- But no correlation between DE and PTPes, PTPdi
- DE influenced by ventilator generated passive movement

Umbrello et al Crit care 2015

Diaphragmatic ultrasound for extubation readiness: The role of thickening fraction

Wan Cley Rabuske [a,b], Georgia Westphal [b], Gustavo Rático [b], Silvano Altair do Nascimento [b], Antuani Rafael Baptistella [a,b,*]

Population	Conducted in Brazil ICU Adult ICU patients (n=128) On invasive mechanical ventilation >24 hours Undergoing SBT with planned extubation
Intervention	Diaphragm Ultrasound performed at 30th minute of T-piece SBT Operators blinded to extubation decision DTF and DE measured (3 value averaged)
Comparator	Between extubation success and failure groups
Outcome	Extubation success or failure within 48 hours Failure defined as: Reintubation or need for NIV due to respiratory failure
Baseline characters	Extubation success: 118 (92.2%) and Extubation failure: 10 (7.8%) Mean MV duration: 5.5 ± 3.0 days Respiratory (25.8%), post-operative (18.7%), neurological (14.1%)

Diaphragmatic Thickening Fraction (DTF)

p=0,042

Diaphragmatic excursion (DE)
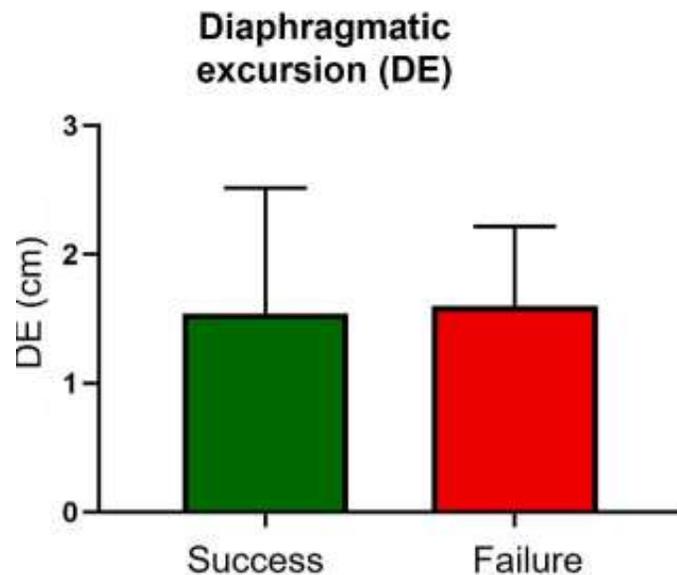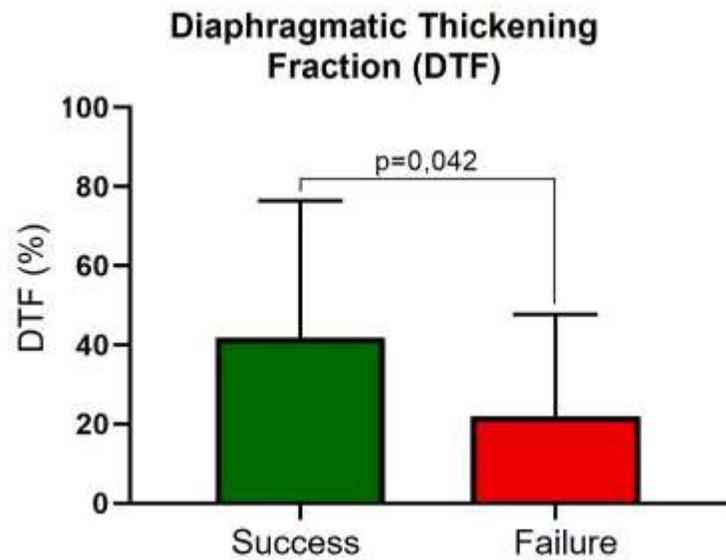
Multivariate regression analysis of the predictors of extubation outcome within 48 h.

	Coefficients				
	Estimated	Standardized	95 % CI	Odds Ratio	p value
Age	−0.072	−1.216	−0.146–0.002	0.931	0.057
Days on MV	−0.004	−0.011	−0.302–0.294	0.996	0.978
APACHE II score	0.063	0.460	−0.118–0.243	1.065	0.496
Sex (male)	−1.159	−1.159	−2.897–0-580	0.314	0.192
DTF	−0.054	−1.568	−0.104 to −0.003	0.948	0.037
DE	−0.123	−0.097	−1.341–1.095	0.884	0.843

DTF is the only independent predictor of extubation success

Small extubation failure group, single time point measurement

Value of Diaphragm Ultrasonography for Extubation: A Single-Blinded Randomized Clinical Trial

Population	Single-center ICU, Brazil Sample size: 40 patients (20 each) Adult ICU patients with respiratory failure receiving mechanical ventilation Exclusion: Neuromuscular disease, MV >14 days, tracheostomy, extensive subcutaneous emphysema
Intervention	**Diaphragm ultrasonography (DUS)–guided weaning** Same standard clinical criteria as control group plus **Diaphragm Thickening Fraction (DTF) >30%** Patient at **45° position,** average of **5 respiratory cycles** Single experienced operator (to reduce interobserver bias)
Comparator	**Conventional weaning protocol** (standard of care) Includes: Spontaneous ventilation >6 h, PR <140 bpm, No respiratory distress, Adequate consciousness (RASS 0–1 / GCS >7), PaO_2/FiO_2 >200, FiO_2 <40%, PEEP <8 cmH_2O, Driving pressure <15 cmH_2O, Stable hemodynamics
Outcomes	Primary outcomes: Reintubation rate and In-hospital mortality Assessed within 48 hours and between day 2 and day 7 post-extubation

- Reintubation <48 h: 0% in both groups

- Reintubation (day 2–7):2 patients (10%) in each group

- DTF showed inverse correlation with inspiratory pressure above PEEP (p = 0.037)

	US	Control	p
Reintubation			
Yes	2 (10%)	2 (10%)	0.598●
No	18 (90%)	17 (85%)	
Death	9 (45%)	7 (35%)	0,374ᵀ

Effectiveness of diaphragmatic ultrasound as a predictor of successful weaning from mechanical ventilation: a systematic review and meta-analysis

Henry M. Parada-Gereda[1*], Adriana L. Tibaduiza[2], Alejandro Rico-Mendoza[3], Daniel Molano-Franco[4],

- 19 studies included in quantitative meta-analysis
  - Sample Size of 1204 adult ICU patients: DE assessed in 908, DTF assessed in 945
  - Mixed ICU populations: medical, surgical, trauma, COPD,ARF
  - Inclusion criteria: Invasive mechanical ventilation >24 h, Ultrasound performed during SBT
  - 12 evaluated DTF and DE, 5 DE, 6 DTF alone
  - 16 studies in semi-recumbent, 3 supine
  - SBT – PS or T tube in most
  - Weaning success - spontaneous breathing ≥48 h post-extubation (varied)

A

Sensitivity (95% CI)

Eltrabili 2019	0,94	(0,71 - 1,00)
Farghaly 2017	0,94	(0,83 - 0,99)
Flevari 2016	1,00	(0,83 - 1,00)
Flevari 2016*	0,85	(0,62 - 0,97)
Flevari 2016**	0,70	(0,46 - 0,88)
Funda Gok 2021	0,70	(0,53 - 0,83)
Hayat 2017	0,78	(0,67 - 0,87)
Huang 2017	0,77	(0,46 - 0,95)
Huang 2017*	0,82	(0,48 - 0,98)
Mawla 2022	0,61	(0,46 - 0,74)
Alam 2022	0,78	(0,52 - 0,94)
Elshazly 2020	0,82	(0,65 - 0,93)
Palkar 2018	0,84	(0,73 - 0,93)
Osman 2017	0,84	(0,71 - 0,93)
Theerawit 2018	0,92	(0,81 - 0,98)
Yoo 2018	0,81	(0,67 - 0,91)
Yoo 2018*	0,66	(0,51 - 0,79)

Pooled Sensitivity = 0,80 (0,77 to 0,83)
Chi-square = 45,86; df = 16 (p = 0,0001)
Inconsistency (I-square) = 65,1 %

Specificity (95% CI)

Eltrabili 2019	0,85	(0,55 - 0,98)
Farghaly 2017	0,86	(0,57 - 0,98)
Flevari 2016	0,71	(0,29 - 0,96)
Flevari 2016*	0,86	(0,42 - 1,00)
Flevari 2016**	0,86	(0,42 - 1,00)
Funda Gok 2021	0,67	(0,22 - 0,96)
Hayat 2017	0,70	(0,47 - 0,87)
Huang 2017	0,68	(0,45 - 0,86)
Huang 2017*	0,60	(0,42 - 0,76)
Mawla 2022	1,00	(0,91 - 1,00)
Alam 2022	0,85	(0,55 - 0,98)
Elshazly 2020	0,96	(0,82 - 1,00)
Palkar 2018	0,69	(0,41 - 0,89)
Osman 2017	1,00	(0,80 - 1,00)
Theerawit 2018	0,55	(0,23 - 0,83)
Yoo 2018	0,69	(0,39 - 0,91)
Yoo 2018*	0,85	(0,55 - 0,98)

Pooled Specificity = 0,80 (0,75 to 0,84)
Chi-square = 49,71; df = 16 (p = 0,0000)
Inconsistency (I-square) = 67,8 %

B

Sensitivity (95% CI)

Abdelwahed 2019	0,94	(0,84 - 0,99)
Dres 2018	0,79	(0,65 - 0,90)
Eltrabili 2019	0,94	(0,71 - 1,00)
Farghaly 2017	0,90	(0,78 - 0,97)
Funda Gok 2021	0,68	(0,51 - 0,81)
Mawla 2022	0,82	(0,69 - 0,92)
Alam 2022	0,61	(0,36 - 0,83)
Elshazly 2020	0,91	(0,76 - 0,98)
Osman 2017	0,88	(0,76 - 0,95)
Pirompanich 2018	0,96	(0,80 - 1,00)
Shigang Li 2021	0,94	(0,86 - 0,98)
Soliman 2019	0,88	(0,78 - 0,94)
Tenza Lozano 2018	0,91	(0,78 - 0,97)
Yoo 2018	0,77	(0,62 - 0,88)
Yoo 2018*	0,68	(0,53 - 0,81)

Pooled Sensitivity = 0,85 (0,82 to 0,87)
Chi-square = 44,81; df = 14 (p = 0,0000)
Inconsistency (I-square) = 68,8 %

Specificity (95% CI)

Abdelwahed 2019	0,79	(0,49 - 0,95)
Dres 2018	0,71	(0,51 - 0,87)
Eltrabili 2019	1,00	(0,74 - 1,00)
Farghaly 2017	0,64	(0,35 - 0,87)
Funda Gok 2021	0,67	(0,22 - 0,96)
Mawla 2022	0,92	(0,79 - 0,98)
Alam 2022	0,77	(0,46 - 0,95)
Elshazly 2020	0,61	(0,41 - 0,78)
Osman 2017	1,00	(0,63 - 1,00)
Pirompanich 2018	0,67	(0,30 - 0,93)
Shigang Li 2021	0,84	(0,67 - 0,94)
Soliman 2019	0,80	(0,56 - 0,94)
Tenza Lozano 2018	0,60	(0,39 - 0,79)
Yoo 2018	0,46	(0,19 - 0,75)
Yoo 2018*	0,62	(0,32 - 0,86)

Pooled Specificity = 0,75 (0,69 to 0,80)
Chi-square = 34,47; df = 14 (p = 0,0018)
Inconsistency (I-square) = 59,4 %

Ultrasound diaphragmatic excursion during non-invasive ventilation in ICU: a prospective observational study

Federico Barbariol[1], Cristian Deana[1], Giovanni Maria Guadagnin[2], Gianmaria Cammarota[3], Luigi Vetrugno[1,4], Flavio Bassi[1]

Population	Single-centre ICU, Italy, n= 47 Adult ICU patients with acute respiratory failure ($PaO_2/FiO_2 < 300$) Non-intubated, planned for a trial of NIV Surgical patients: 38%, High proportion of hepatic surgery / liver transplant, COPD 24%
Intervention	Diaphragm ultrasound performed at two time points: T0: before starting NIV and T1: after 1 hour of NIV DE was assessed NIV settings: Pressure support 5–7 cmH_2O and PEEP 5–10 cmH_2O Sedation (if needed): remifentanil Definition of diaphragmatic dysfunction: DE < 1.0 cm
Comparator	Patients with diaphragmatic dysfunction vs without DD NIV responders vs NIV non-responders Comparison of baseline DE as a predictor of NIV success/failure

- Primary outcome: Prevalence of diaphragmatic dysfunction – 42.5% (95% CI 28.3 – 57.8)
- More prevalent in surgical than medical
- **Mean baseline DE:**
  - NIV responders: **1.35 ± 0.78 cm**
  - NIV non-responders: **1.21 ± 0.85 cm**
- Diaphragm excursion increased: **+0.20 cm** during NIV (p = 0.001)

- Response to NIV at 1 hour
- NIV failure at T1:
  - PaO_2 increase < 50%
  - $PaCO_2$ increase > 15%
  - Respiratory rate > 40/min
- **NIV success rate:**
  - With DD: **60%**
  - Without DD: **70.4%**
- No difference between success and failure

Barbariol et al Acta Biomed. 2021 Jul 1;92(3):e2021269

A)
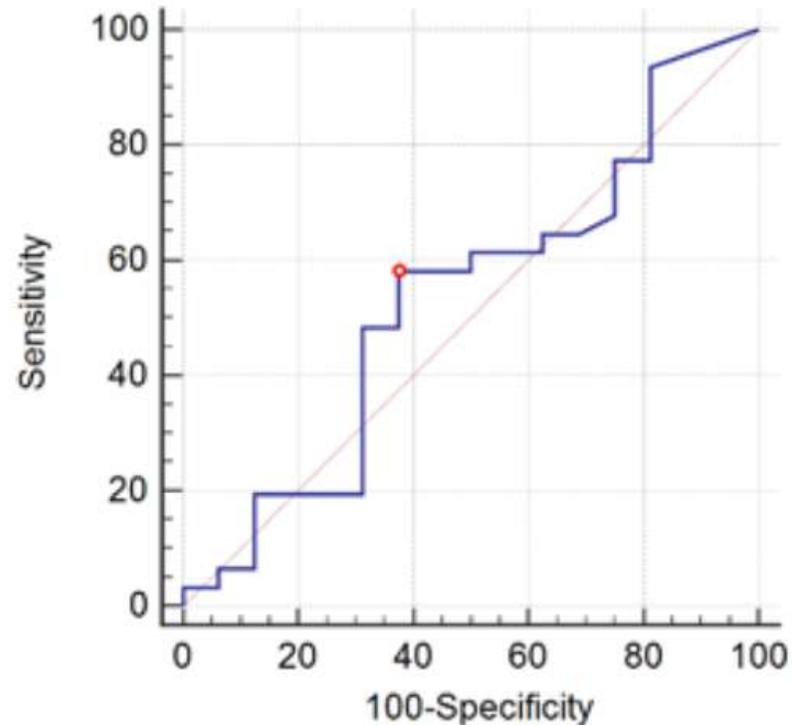
B)
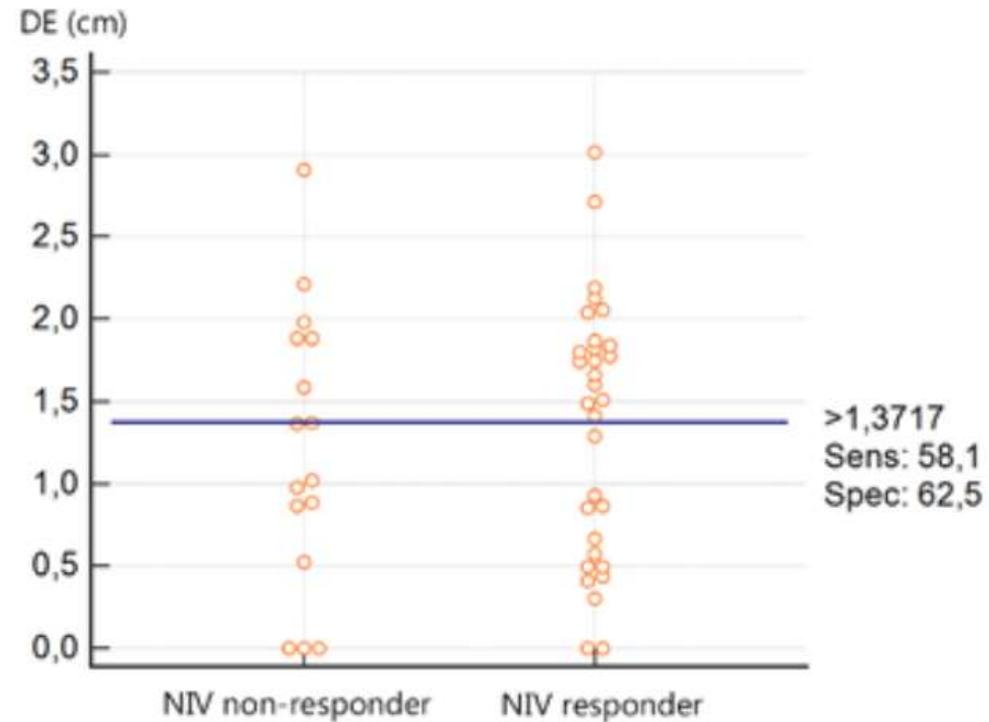
ROC analysis DE predicting NIV success: **AUC = 0.53** (95% CI 0.38–0.68)
Best cut-off: **DE = 1.37 cm,** Sensitivity **58.1%** and Specificity **62.5%**

DE is Influenced by positive pressure and reflects movement, not force generation
Failed to predict outcomes.

Barbariol et al Acta Biomed. 2021 Jul 1;92(3):e2021269

Role of diaphragm US in ventilator asynchrony

- Visual inspection of airway flow and pressure waveforms can detect asynchrony

- But unreliable

- Esophageal pressure and diaphragm electrical activity are gold standard for detecting asynchrony

- But invasive techniques

- Esophageal pressure and diaphragm displacement correlated

Soeilimezi et al, Am J Respir Crit Care Med 2019, 201901
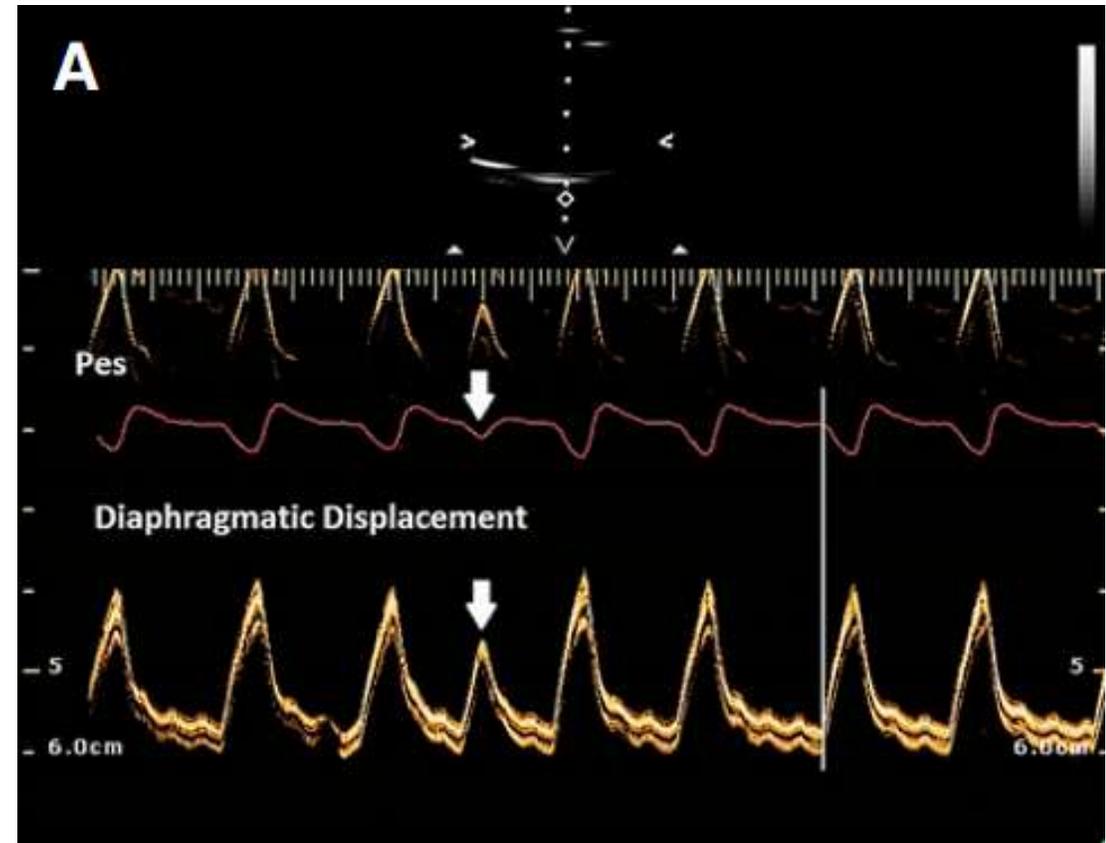
Double trigger
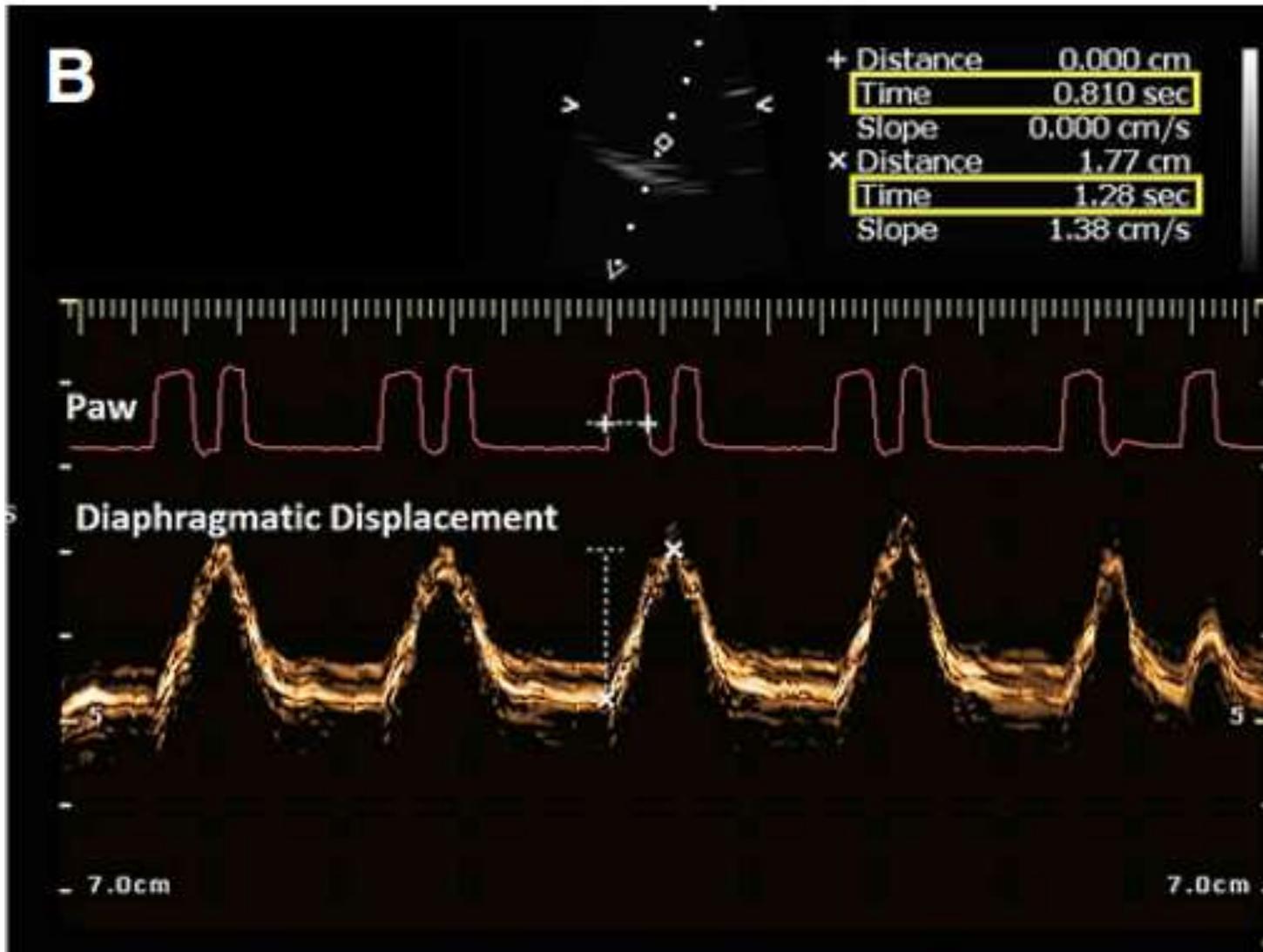
Neurological Ti > Mechanical Ti

Ventilator delivers two consecutive breaths for a single patient's effort

Soeilimezi et al, Am J Respir Crit Care Med 2019, 201901

Ineffective trigger

Soeilimezi et al, Am J Respir Crit Care Med 2019, 201901
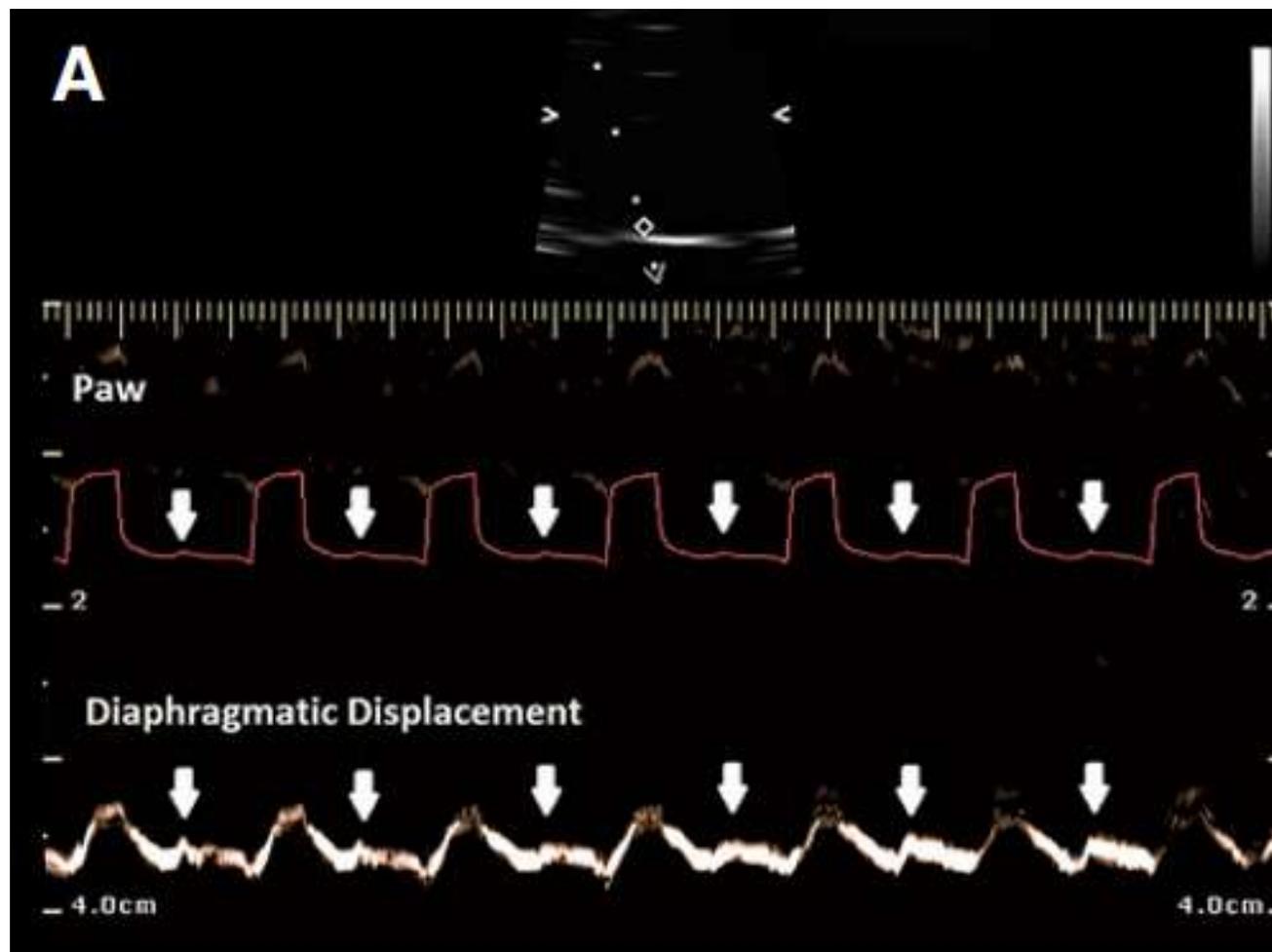
Reverse trigger
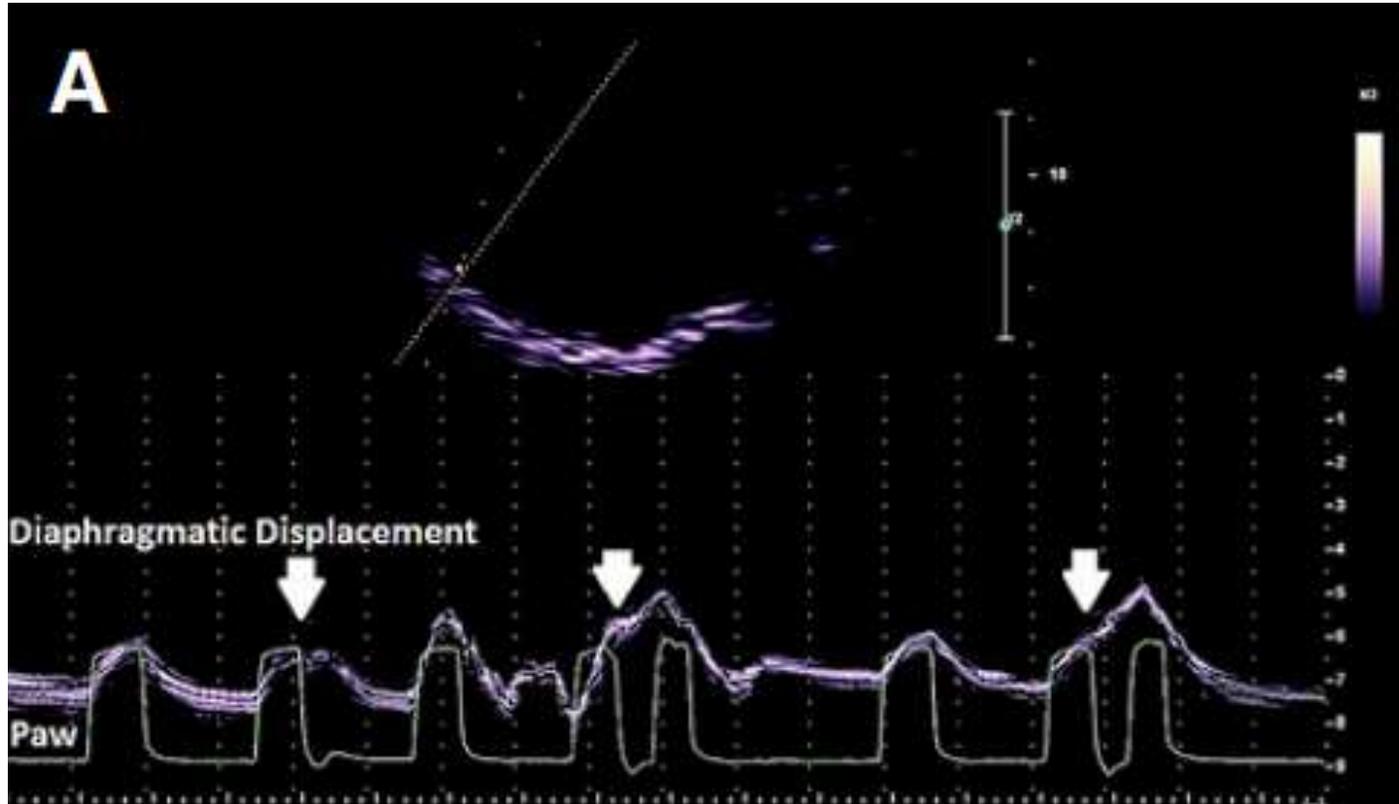
- Active diaphragm excursion after passive displacement
- Higher excursion amplitude and change in displacement slope

Laryngeal ultrasound in ICU

Why is predicting extubation failure important?

- Extubation failure occurs in 10–20% of ICU patients

- Upper airway causes account for 30–40% of extubation failures

- Common mechanisms:
  - Laryngeal edema
  - Vocal cord dysfunction/paresis
  - Reduced airway caliber after prolonged intubation

- Post-extubation stridor incidence: 4–15%

- Cuff leak test: Meta analysis shows low sensitivity 62% and good specificity 87% for post-extubation airway obstruction

- Influenced by tube size, secretions, and lung compliance, and cannot identify the cause of obstruction

Fracois B et al Lancet 2007
Arnaud W et al AJRCCM 2013
S Jaber et al Int Car Med 2003
Kuriyama et al Crit care 202

Laryngeal ultrasound

- Bedside, non-invasive point-of-care ultrasound technique used to assess:
  - Vocal cord structure and motion
  - Laryngeal soft tissues
  - Subglottic airway caliber
- Can be performed in intubated and extubated patients, without sedation or airway manipulation
- Based on previous studies
  - Vocal cord motion with fiberoptic laryngoscopy – high agreement
  - Air column width with fiberoptic laryngoscopy – mod to high agreement

Zamora et al Ann Int Care 2019
Ding W et al Crit Care 2016

What structures are assessed in laryngeal US?

- visualizes the anterior neck structures using a high-frequency linear probe (7–15 MHz)

- At the level of vocal cords, B mode

- In supine position, neck in neutral or mild extension

- Parameters assessed:

Vocal cord mobility	Symmetry and range of motion	Inter-observer agreement K = 0.8
Air Column Width (ACW	Measured between vocal cords	K = 0.85
Air Column Width Difference (ACWD)	Before vs after cuff deflation	K = 0.88

Reduced visualization in: Elderly males (thyroid cartilage calcification) and obese

- **Transverse (axial) View:** Probe transversely over thyroid cartilage
  - Vocal cord motion (paired hyperechoic bands)
  - Measuring **air-column width** - Air–mucosal interface (bright echogenic line)

- **Longitudinal (sagittal) View:** Probe in midline
  - Identifying the **cricothyroid membrane** in difficult airway
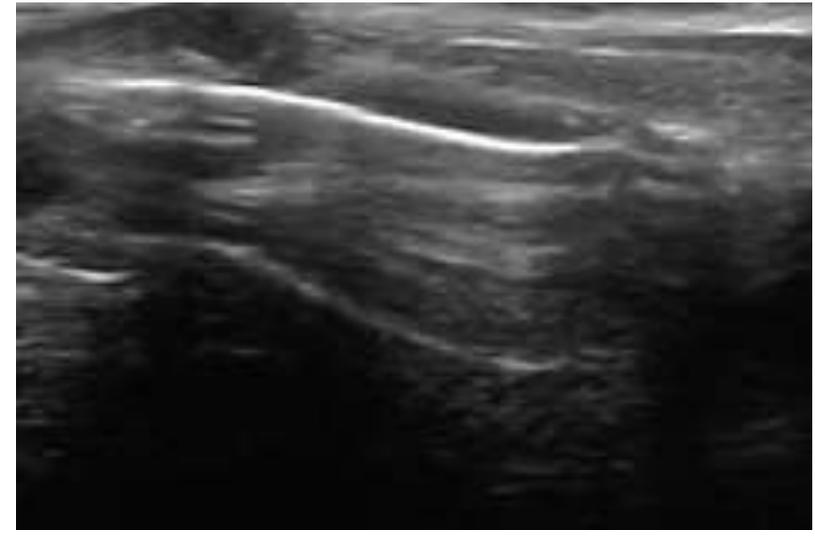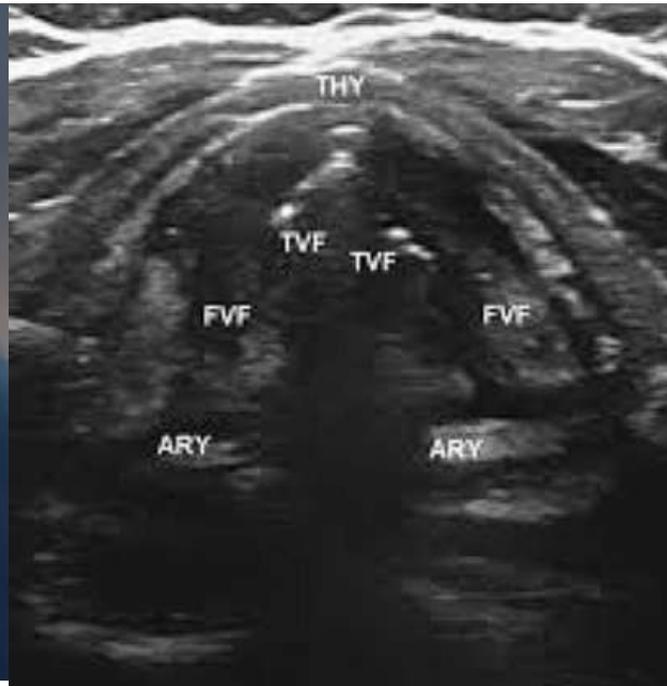
ACW and ACWD
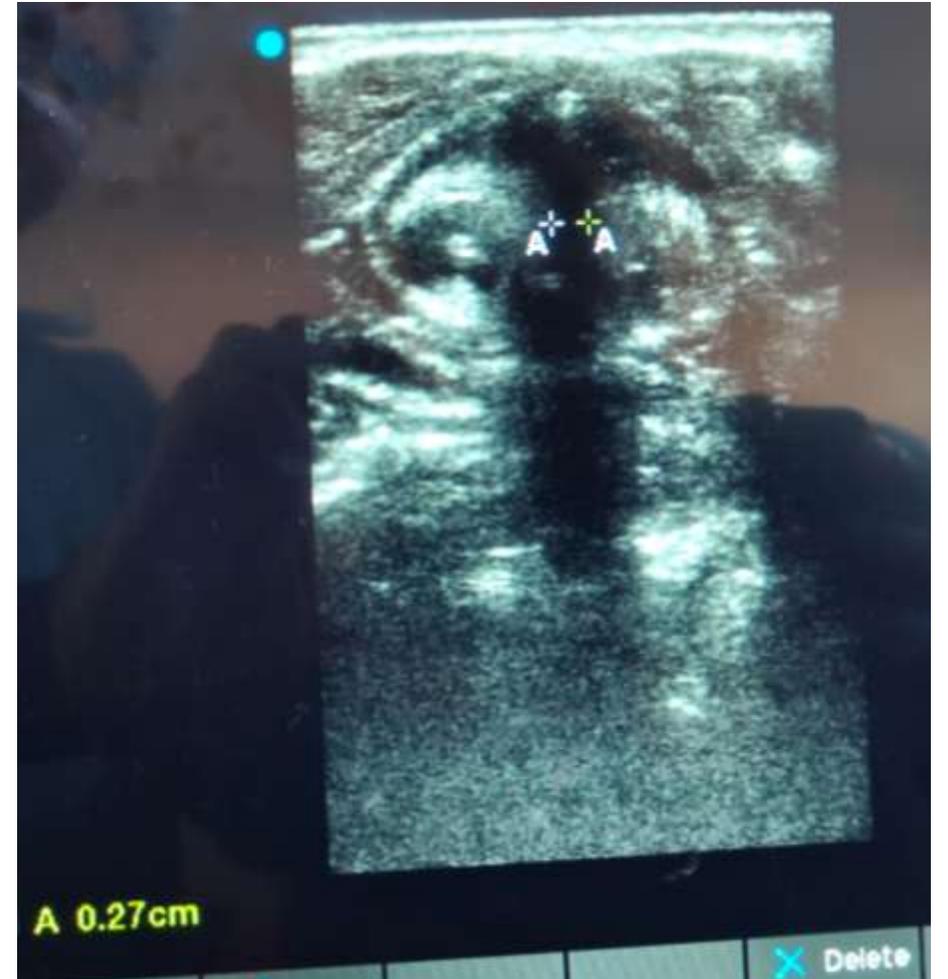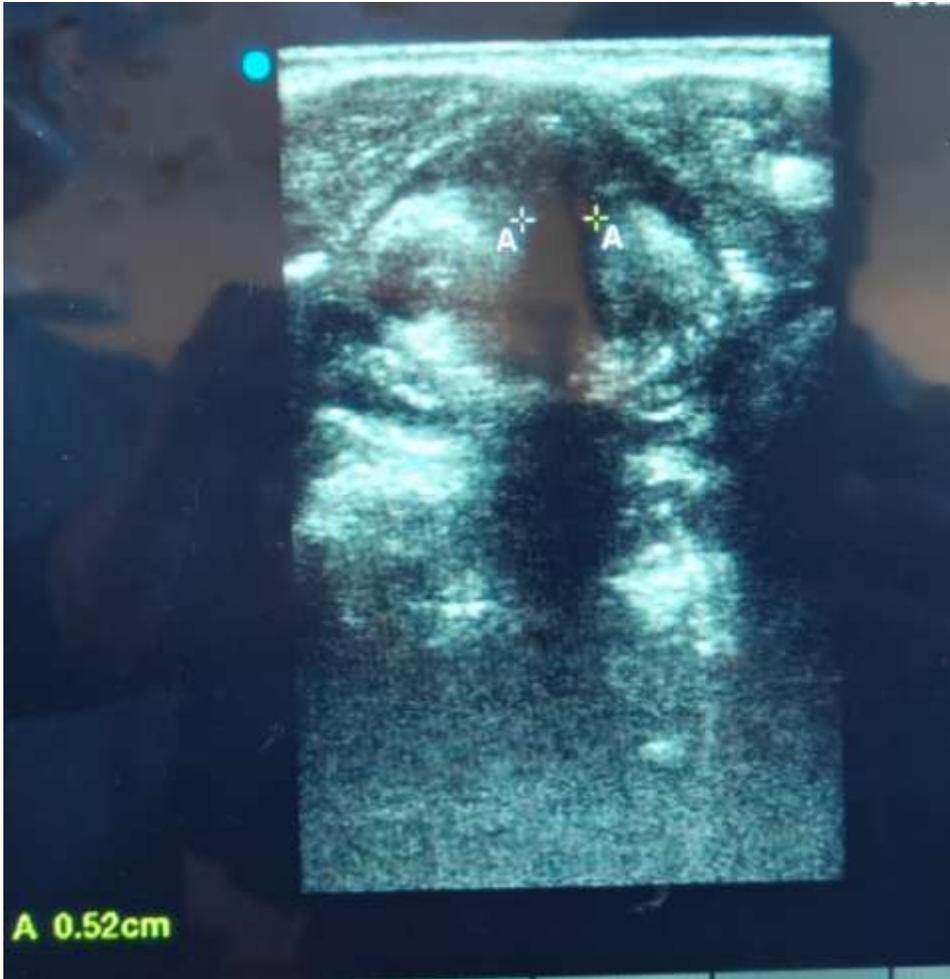
Laryngeal ultrasound: a useful method in predicting post-extubation stridor. A pilot study

L-W. Ding*,#, H-C. Wang*,¶, H-D. Wu+, C-J. Chang§ and P-C. Yang*

Population	Single ICU in Taiwan, N=51 Adult patients admitted to a medical ICU, Mechanically ventilated ≥24 hours and planned extubation
Intervention	Pre-extubation laryngeal ultrasonography performed within 24 hours before extubation Measured Air-column width during cuff deflation and Air-column difference (cuff inflated vs deflated) Cuff leak test , Operators blinded to cuff-leak results Ventilator settings: assist-control mode with 5 cmH2O of PEEP and adjusted VT until the PIP 30 cmH2O.
Comparator	Fiberoptic bronchoscopy findings Compared between patients with and without post-extubation stridor
Outcome	Primary outcome: Development of post-extubation stridor – 7.8% (4) Secondary outcome: Re-intubation rate - 9.8% Air column width during cuff deflation: Stridor group: **4.5 mm (IQR 0.8) vs** Non-stridor group: **6.4 mm (IQR 2.0), p=0.01**

Cuff-leak volume, air-column difference and air column width during BD were significantly different between the stridor and the non stridor groups.

	Nonstridor[#]	Stridor[¶]	p-value[+]
Age yrs	71 (20)	67 (10.5)	0.57
Intubated days	6 (7)	7 (6)	0.99
Sex male n (%)	34 (72.3)	1 (25)	0.04[§]
Cuff-leak volume mL	300 (350)	25 (20)	<0.01[§]
Peak airway pressure difference cmH$_2$O	6 (8)	3.5 (1.8)	0.08
Air-column width on BD mm	6.4 (2)	4.5 (0.8)	0.01[§]
Air-column difference mm	1.5 (1.3)	0.35 (0.5)	<0.01[§]
ETT size mm	7.5 (0)	7.5 (0.30)	0.51
6.5 n (%)	2 (4.3)	0 (0)	
7.0 n (%)	5 (10.6)	1 (25)	
7.5 n (%)	36 (76.6)	3 (75)	
8.0 n (%)	4 (8.5)	0 (0)	

Ding et al Eur Resp Jour 2006

Predicting laryngeal edema in intubated patients by portable intensive care unit ultrasound[☆,☆☆,★]

Yuda Sutherasan MD*, Pongdhep Theerawit MD, Tanasit Hongphanut MD, Charn Kiatboonsri MD, Sumalee Kiatboonsri MD

Laryngeal ultrasound versus cuff leak test in prediction of post-extubation stridor

Mai A. Sahbal, Kamel A. Mohamed, Hanan H. Zaghla, Mahmoud M. Kenawy[*]

Population	Prospective observational study, Bangkok, n=101 Adult medical ICU patients (≥18 years) Intubated and planned for extubation	Prospective observational study, Egypt, n=50 Adult medical ICU patients Intubated ≥24 hours and planned for extubation
Intervention	Pre-extubation laryngeal ultrasound Measured **Air Column Width Difference (ACWD)** Ventilator settings: assist-control mode, VT 10ml/kg, Flow rate 50L/min, PEEP 5 cm H2o, Fio2 40%	Pre-extubation laryngeal ultrasound ACW and ACWD Ventilator settings: Not mentioned
Comparator	Quantitative cuff leak test Reference standard: Video laryngoscopy + clinical stridor Compared between patients with and without laryngeal edema	Cuff leak test Reference: Post-extubation stridor

Sutherasan et al Jor Crit Care 2013
Sahbal et al EJCCM 2017

Baseline	Prevalence of laryngeal edema: 16.8% Mean duration of intubation: 6.4 ± 8.9 days Mean ACWD: • LE group: 1.08 ± 0.81 mm • No-LE group: 1.99 ± 0.79 mm (p < 0.001)	• Post-extubation stridor (PES) incidence: 8% (4/50) • ACW before deflation: 11.54 ± 0.72 mm in PES group vs 11.27 ± 0.57 mm (p= 0.43) • ACWD: 0.95 ± 0.08 mm in PES vs 0.97 ± 0.09 mm (p=0.83)
Outcome	Primary outcome: Diagnostic accuracy of ACWD for predicting laryngeal edema ACWD cutoff: ≥ 1.6 mm Sensitivity: 70.6%, Specificity: 70.2%, PPV: 32.4%, NPV: 92.2%	Primary outcome: Ability of laryngeal US vs CLT to predict post-extubation stridor CLT cutoff: 132.5 mL, Sensitivity: 75%, Specificity: 93.5%, PPV: 50%, NPV: 97.7% ACWD cutoff: 0.905 mm, Sensitivity: 50%, Specificity: 73.9%, PPV: 14.3%, NPV: 94.4%

Sutherasan et al Jor Crit Care 2013
Sahbal et al EJCCM 2017

Diagnostic efficacy of laryngeal ultrasound (ACWD) for predicting post-extubation stridor – Meta analysis

- Included 11 studies (6 from Egypt, 2 from India, 1 from USA)

- 4 studies had n > 100

- PES incidence: 4–25%

- ACWD cutoff values: 0.45 – 1.6 mm (no prespecified cut-off in 3 studies)

- Risk of bias was low in all domains except the index test due to a lack of pre defined cut-off

- Primary outcome: Diagnostic efficacy of ACWD in predicting PES

- Secondary outcomes: differences in ACWD and the duration of tracheal intubation between patients with and without PES

- Diagnostic criteria of PES varied across studies
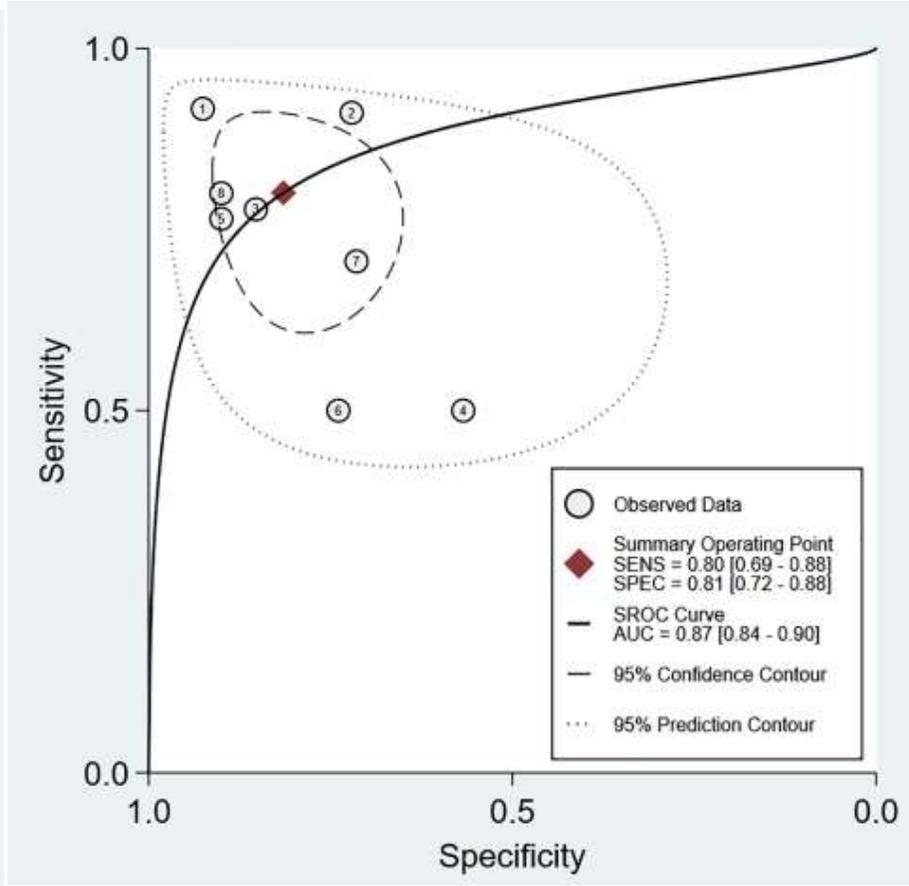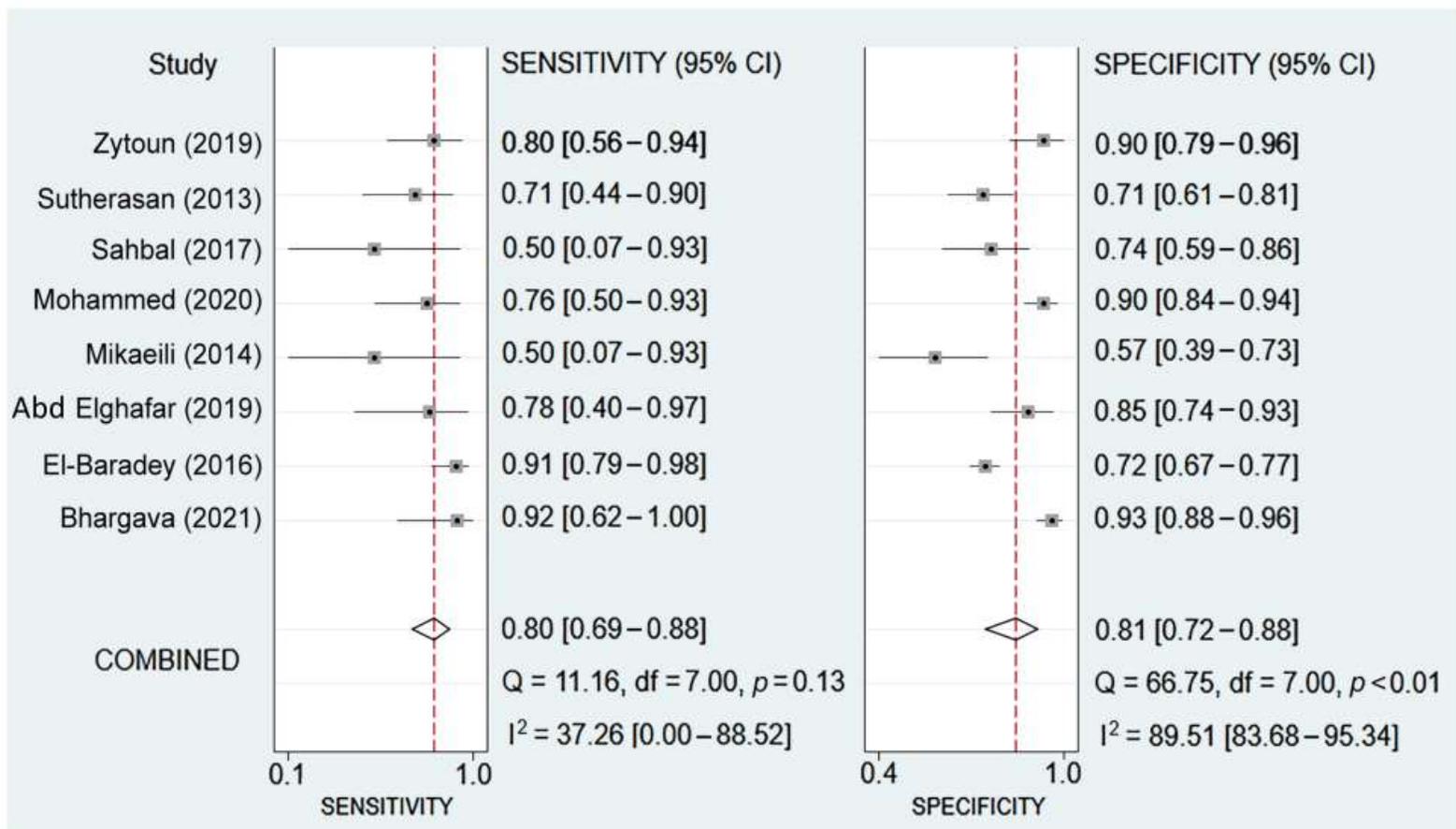
Compared to CLT (sensitivity 62% and specificity 87%) laryngeal ACWD had better diagnostic performance in predicting PES

Tsai et al Fron Med 2023
Kuriyama et al 2020

	ACWD (PES)			ACWD (non-PES)				Mean Difference	Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI	IV, Random, 95% CI
Abd Elghafar 2019	1.14	0.7	9	1.78	0.53	61	9.6%	-0.64 [-1.12, -0.16]	
Bhargava 2021	0.13	0.03	12	0.29	0.026	188	14.2%	-0.16 [-0.18, -0.14]	
El-Baradey 2016	0.6	0.5	45	1.9	0.7	387	13.5%	-1.30 [-1.46, -1.14]	
Hasan 2019	0.56	0.07	7	0.86	0.5	51	13.6%	-0.30 [-0.45, -0.15]	
Mohammed 2020	0.541	0.33	17	1.237	0.44	150	13.4%	-0.70 [-0.87, -0.52]	
Patel 2015	0.4	0.2	2	0.8	0.7	49	11.4%	-0.40 [-0.74, -0.06]	
Sahbal 2017	0.95	0.08	4	0.97	0.09	46	14.0%	-0.02 [-0.10, 0.06]	
Sutherasan 2013	1.08	0.81	17	1.99	0.79	84	10.3%	-0.91 [-1.33, -0.49]	
Total (95% CI)			113			1016	100.0%	-0.54 [-0.79, -0.28]	

Heterogeneity: Tau² = 0.12; Chi² = 257.06, df = 7 (P < 0.00001); I² = 97%
Test for overall effect: Z = 4.08 (P < 0.0001)

	intubation days (PES)			intubation days (non-PES)				Mean Difference	Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI	IV, Random, 95% CI
Abd Elghafar 2019	7.78	1.99	9	2.25	0.77	61	15.5%	5.53 [4.22, 6.84]	
El-Baradey 2016	14.3	4.5	45	9.6	2.2	387	15.4%	4.70 [3.37, 6.03]	
Hasan 2019	7.23	2.71	7	6.53	2.14	51	13.8%	0.70 [-1.39, 2.79]	
Mohammed 2020	10.59	3.02	17	5.87	4.76	150	14.9%	4.72 [3.09, 6.35]	
Patel 2015	3.5	0.71	2	3.86	3.51	49	15.3%	-0.36 [-1.75, 1.03]	
Sutherasan 2013	7.85	7.5	17	6.15	9.23	84	9.2%	1.70 [-2.38, 5.78]	
Venkategowda 2015	5.6	1.14	5	3.91	1.45	67	15.9%	1.69 [0.63, 2.75]	
Total (95% CI)			102			849	100.0%	2.75 [0.92, 4.57]	

Heterogeneity: Tau² = 5.15; Chi² = 57.90, df = 6 (P < 0.00001); I² = 90%
Test for overall effect: Z = 2.95 (P = 0.003)

Tsai et al Fron Med 2023

Role in post-extubation monitoring

Population	Single-center ICU in Egypt, n=432 patients Adult ICU patients, mechanically ventilated ≥24 hours and ready for planned extubation
Intervention	• **Laryngeal ultrasound–guided Air Column Width Difference (LACWD)** • **Cuff Leak Volume (CLV)** Both measured before extubation **Steroid therapy for PES -** Dexamethasone 8 mg IV every 8 h for 3 days Repeat LACWD and CLV after steroid therapy to assess edema regression Standardized ETT size (7.0–7.5 mm), cuff pressure 20–25 cmH$_2$O
Comparator	Compared between PES vs no-PES and within the PES group, before vs after dexamethasone Diagnostic comparison between LACWD and CLV for predicting PES and response to steroids
Baseline	**Post-extubation stridor (PES): 45 (10.5%)** Risk factors for PES - Longer duration of intubation (14.3 ± 4.5 vs 9.6 ± 2.2 days), female sex and younger age Baseline values (PES vs No-PES): • CLV: 144.7 ± 112 mL vs 286.7 ± 123 mL (p = 0.002) • LACWD: 0.6 ± 0.5 mm vs 1.9 ± 0.7 mm (p < 0.001)

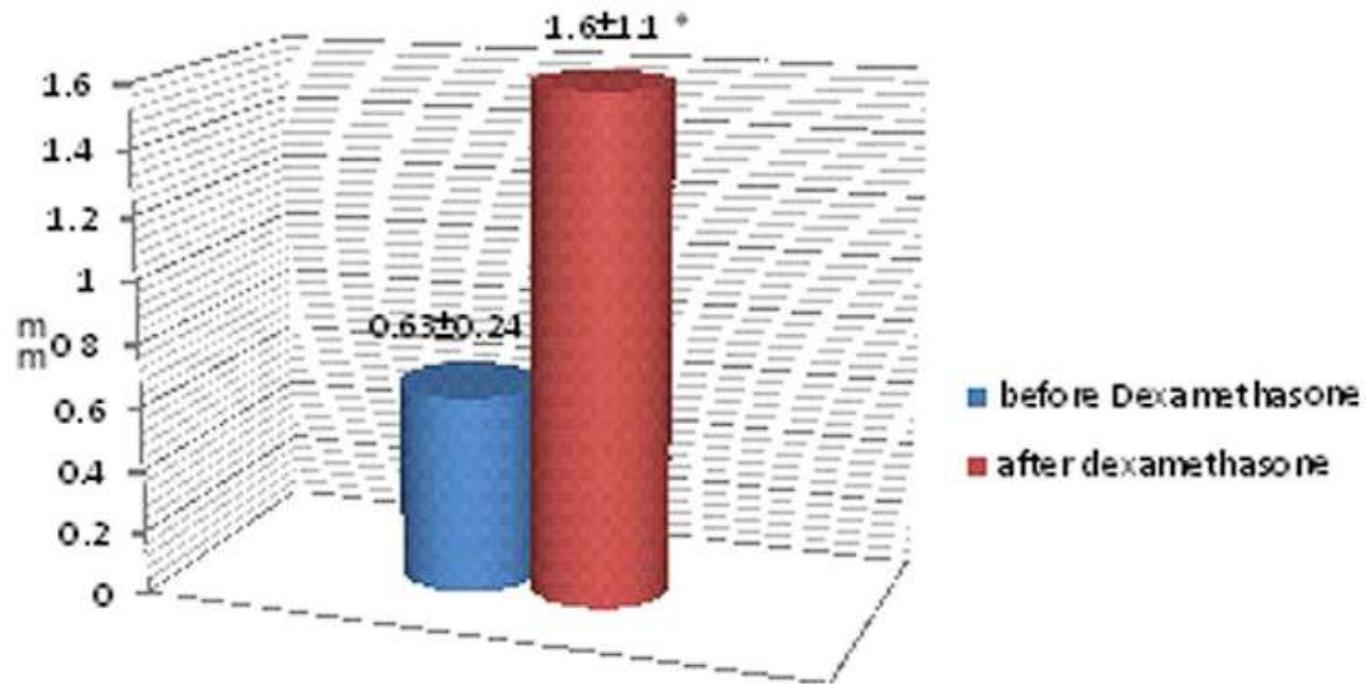El Baradey GF et al. Journal of Critical Care. 2016;36:272–276

Fig. 3. LACWD (mm) before and after dexamethasone treatment.

All 45 patients with PES received steroids
18 recovered without re-intubation
27 re-intubated
After steroids: 19 successfully extubated and 8 required tracheostomy

Sensitivity, specificity, positive and negative predictive value for both CLV and LACWD in predicting PES in all patients

Variables	Cut-off value	Sensitivity	Specificity	PPV	NPV	Accuracy
CLV	<200 mL	94%	65%	97%	66%	94%
LACWD	<0.9 mm	91%	72%	97%	50%	92%

El-Baradey GF et al. Journal of Critical Care. 2016;36:272–276

Role in predicting and guiding tracheostomy

- Tracheostomy complication rates range from 5-15%

- **Bleeding** accounts for **30-40%** of major complications

- Surface landmarks are **unreliable** in obesity, short neck, and edema

- Pre-procedural US assessment:
  - Tracheal midline & inter-ring spaces: US changes **puncture site** in 24% in a study with PDT
  - Thyroid isthmus position: 20-30% cases identified overlying the target site
  - Pretracheal vessels: 25-40% in ICU patients, aberrant vessels at the puncture site
  - Tracheal depth (skin-to-trachea distance): **> 25 mm** associated with increased procedural difficulty, like misposition, bleeding

Hatfield A et al., *Br J Anaesth*, 2011
Rajajee V et al., *Crit Care Med*, 2011
Kollig et al, Injury 2000, 31 (9): 663–68

Intra-procedural Ultrasound Guidance for Tracheostomy

- First pass success in PDT:
  - US-guided: 85–95%, Landmark: 65–75%

- Major bleeding in PDT:
  - US-guided: 0–2%, Landmark: 5–8%

- Study by Sustic et al showed significantly reduced posterior tracheal wall injury with US guidance and procedure time 8 vs 21 mins

- Same study also found 33% in the landmark group had cranially displaced tracheostomy tubes (between the cricoid cartilage and the first tracheal ring) but no cranial misplacement in the real-time ultrasound group (P < 0.05).

- Another study in 50 consecutive patients classifies based on BMI. Median BMI was 34 vs. 25, (P < 0.001) between groups.

- No difference in time required or complication rate. But location of tracheal puncture changed in 50% of obese patients due to aberrant vasculature in 32%.

Guinot PG Crit Care 2012; 16 (2): R40.
Rajajee V et al Crit Care 2011; 15 (1): R67

Summary – Diaphragm USG

How to perform	Position: Semi-recumbent (30–45°) Prerequisites: Stable respiratory drive, minimal or no pressure support 2 Approaches: • Subcostal (2–5 MHz curvilinear) Between parasternal and Anterior axillary line: Diaphragm excursion (M-mode) • Intercostal (7–12 MHz linear) Between AXL and MAL 8th-10th ICS: Thickness & thickening fraction (DTF) (B-mode) Measure average of 3 breaths, right hemidiaphragm preferred
Evidence available	• Assessment of respiratory effort during assisted ventilation - DTF correlates strongly with PTPes & PTPdi • Prediction of extubation success - DTF performs better than excursion • Meta-analysis: DTF: Sensitivity 87%, Specificity 75% • Outcome prediction in NIV - poor evidence
Caveat	No single best cutoff No reintubation or mortality benefit DE affected by ventilatory support

Summary – Larynx USG

How to perform	Position: Supine, neck neutral or mildly extended Probe: High-frequency linear (7–15 MHz) Views: - Transverse (thyroid cartilage): Vocal cord motion, air column width, ACWD - Longitudinal (midline): Cricothyroid membrane, airway landmarks Can be done intubated or extubated, no sedation required
Evidence available	Prediction of post-extubation stridor (PES): ACWD correlates with PES - Meta analysis: ACWD sensitivity 80%, specificity 81% - Better sensitivity than cuff-leak test Post-extubation monitoring; Regression of edema after steroids
Caveat	Variable cutoffs Variable views in obese and edema Needs standardization

Thank you