Electrical Impedance Tomography Assisted Ventilation and Oxygenation Management of Adult ECMO Patients

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Disclosures

- Sponsored talk by Timpel Medical

Content

- Recent EIT in Respiratory Care Journal
- Specific aims of project
- Background and significance
- How EIT is set up
- Preliminary data
  - Patient A: Influenza, MSSA pneumonia, Aspergillosis resulting in ARDS
  - Patient B: Influenza resulting in ARDS and Acute Renal Failure
- Results and graphs
- Research plan moving forward

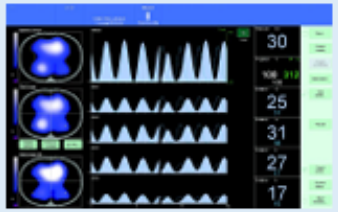
About me

- Registered Respiratory Therapist for over 16 years
- Background of working with all age groups
- Graduate from Bachelor’s of Health Sciences from University of Missouri
- Obtained Certified ECMO Specialist – Adult Credential from International Board of Blood Management
- Current role of ECMO Program Coordinator for University of Missouri Health Care

Electrical Impedance Tomography: What the Editors Are Saying

What Is Known:

- Electrical impedance tomography (EIT) is a noninvasive, radiation-free imaging technique that measures impedance to monitor distribution of ventilation.
- EIT is a bedside portable device used to provide real-time lung imaging data.
- Distribution of ventilation measured by EIT has been validated against computed tomography (CT).
- The most common application of EIT is monitoring invasive mechanical ventilation.



What Others Are Saying:

- Compared to CT, EIT was found to be accurate and consistent in measuring regional dynamic ventilation. Katayama. Crit Care 2024
- EIT was utilized to identify phenotypes of ventilation patterns associated with increased postoperative pulmonary complications. Iwata. Am J Respir Crit Care Med 2024
- A comparison of airway pressure release ventilation (APRV) and low tidal volume ventilation that utilized EIT to assess outcomes revealed APRV may lead to better gas exchange and compliance. Zhang. Chest 2024

What We Are Saying:

- Decreased time on ECMO was associated with use of EIT guided recruitment maneuvers and surfactant administration in neonates with ARDS. Clausen. Respir Care 2024
- EIT assessment after prone position sessions in adults with ARDS identified increased lung recruitment after consecutive sessions and dorsal-lung de-recruitment 2 hours afterwards. Pupier. Respir Care 2024
- Evaluation of 3 PEEP titration methods monitored by EIT in adults with COVID-19 related ARDS revealed that all effectively improved oxygenation. Lopes de Novaes. Respir Care 2024

Take-Home Message: While not considered a diagnostic tool, EIT provides an alternative to CT to evaluate distribution of ventilation at the bedside. EIT may be useful for optimizing and individualizing mechanical ventilation for adults and children.

RESPIRATORY CARE

Specific Aims of Project

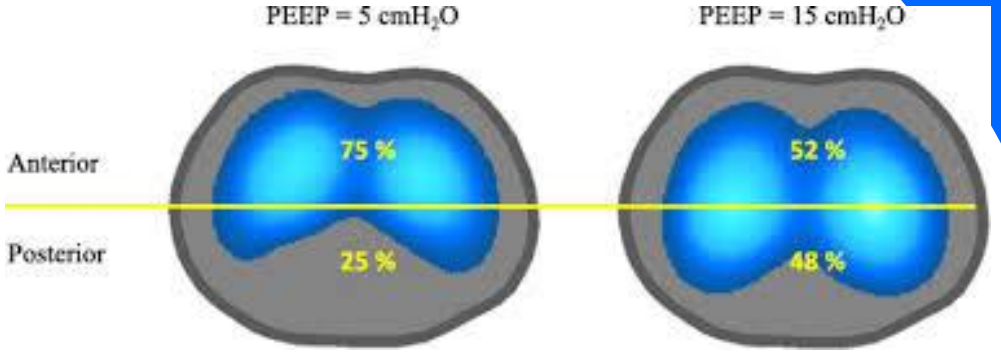
1. Utilizing EIT to manage ventilation and oxygenation of ECMO pts by optimizing PEEP (peak end expiratory pressure)

2. Utilizing EIT to:
   a) Monitor ventilation distribution pre and post bronchoscopy and document change and/or improvement
   b) Monitor ventilation distribution to determine necessity of recurrent bronchoscopies or other procedures/intervention

Background

- Electrical impedance tomography (EIT) is a bedside, noninvasive, radiation-free technology, that can help determine optimal peak end expiratory pressure (PEEP) through real-time dynamic lung mechanics analyses, to improve oxygenation and ventilation, while reducing hyperdistention and collapse.

- This technology can be useful in the management of patients with acute respiratory distress syndrome (ARDS) who are difficult to ventilate and oxygenate.



Background and significance

- Venous-venous extracorporeal membrane oxygenation (VV ECMO) can be used to limit ventilator-induced lung injury (VILI) in patients with reversible, refractory hypoxia to conventional treatment.

- VV ECMO limits VILI by allowing for ventilator changes to tidal volume and PEEP with resultant decreased peak airway pressures, driving pressures, whilst facilitating oxygenation and ventilation. The optimal ventilator settings to apply whilst patients are on ECMO remain not well defined.

- Optimal PEEP can be defined as PEEP that:
  - Provides appropriate gas-exchange
  - Keeps the lungs open (prevents phasic airway collapse)
  - Avoids alveolar over-distension
  - Does not compromise hemodynamics

Background and significance

- Patients with ARDS (acute respiratory distress syndrome) receiving MV (mechanical ventilation) are at risk of developing VILI (ventilator induced lung injury).

- These insults include, but are not limited to:
  - Damage from high volume (volutrauma-lung stress)
  - Injury from high pressures (barotrauma-lung strain)
  - Atelectrauma from repeated opening and closing of the alveoli due to low lung volumes
  - Biotrauma, a particularly harmful form of lung injury due to the body's response to tissue damage that may result in other organ failure.

Background and significance

- Our institution follows the ELSO guidelines for MV settings that recommend inspiratory plateau pressure < 25 cmH20, PEEP $\geq$ 10 cmh20, RR 4-15 bpm or spontaneous breathing and FiO2 goals $\leq$ 40%.
- Caio et al. demonstrated in a prospective study of patients intubated for ARDS related to COVID-19, that there was a change in compliance in 59% of patients when changing from supine to prone position. In almost half of those patients PEEP had to be changed by 4cmH20 to achieve best compliance.

Methods and patient selection

EIT was used to measure and adjust PEEP based on lung compliance and distribution of ventilation with patients in various positions. Ventilator settings and ECMO parameters were adjusted to minimize lung injury and improve oxygenation.

- Patient A: Influenza, MSSA pneumonia, Aspergillosis resulting in ARDS
  - 10 days MV, 45 days on ECMO, 84 days total in hospital until discharge home for OPR, trach removed before discharge
- Patient B: Influenza resulting in ARDS and Acute Renal Failure
  - 6 days MV, 12 days ECMO, 38 days total in hospital until discharge home for OPR, trach removed before discharge
  - Patient also had notable larger body habitus

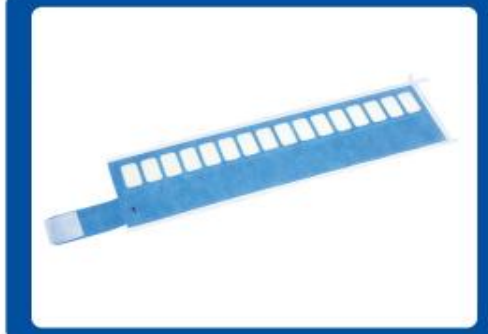
Procedure of PEEP Titration

- The Enlight 2100 device made by Timpel Medical was the EIT machine used in this case report. The device has belts with 32 electrodes that applied on the patient's chest.
- PEEP was set at 15-22cmH20, decay threshold of 2 cmH2O, and countdown time of 30 seconds.
  - After each successful measurement, the PEEP was titrated on the ventilator by 2cmH2O, the EIT would record the decrease in PEEP and then begin the 30 second countdown.

ENLIGHT 2100 & Accessories

Sensoring Reusable Belt

- No chest compression, comfortable for the skin
- Left & Right (two) separated parts for easy application
- 32 electrodes provide the highest resolution with the most dense image quality available

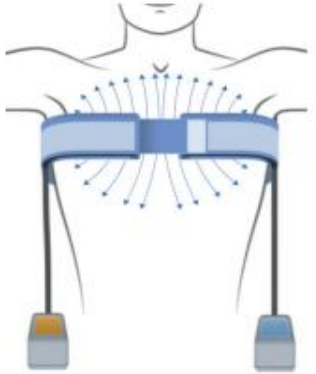


Addere

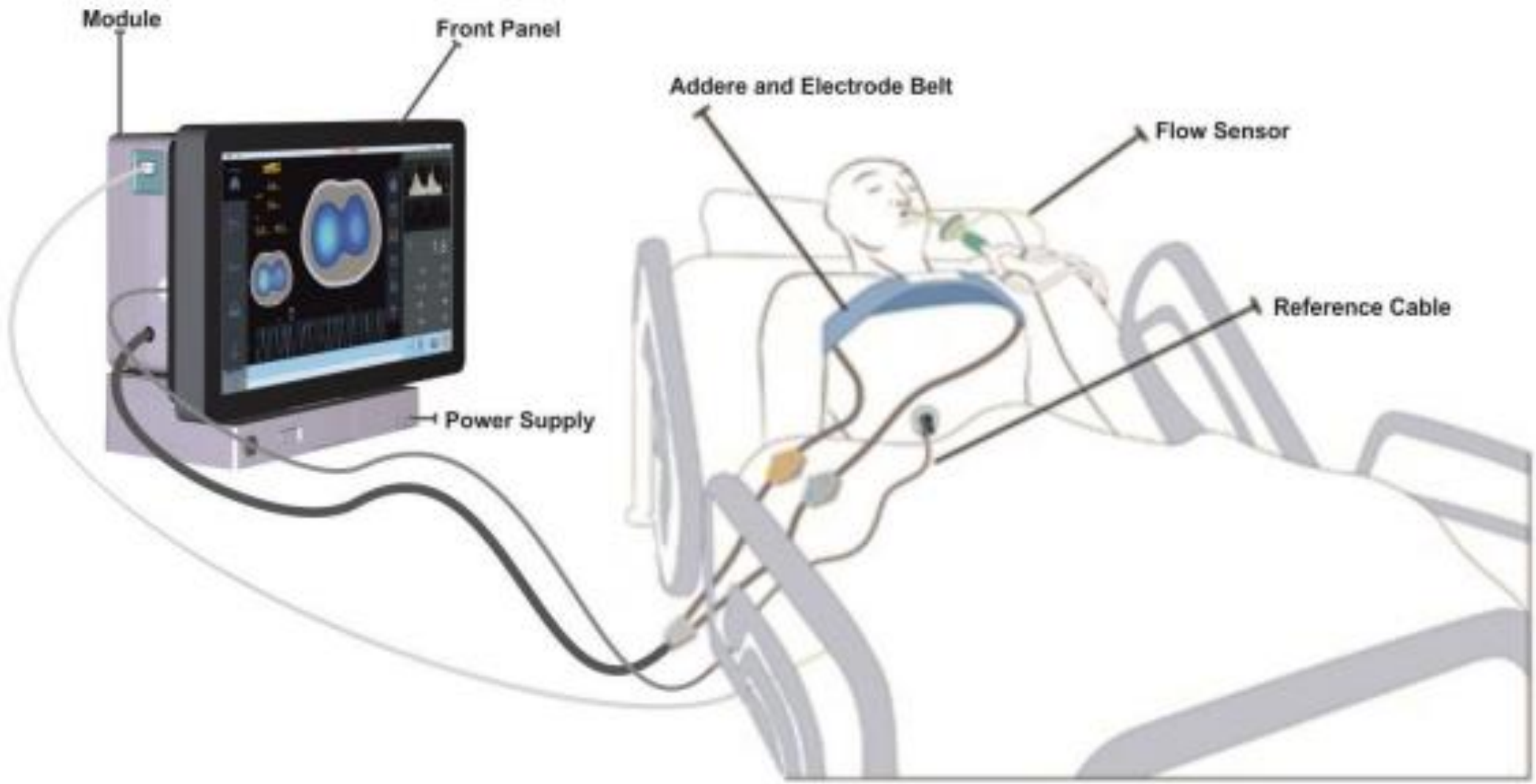
- Breathable, textile non woven fabric
- Single patient use to minimize the chances of cross infection
- Highly conductive biocompatible gel, for gentle contact on the patient's skin, avoiding belt misplacement
- Provides excellent signal quality
- Up to 48 hours of continuous monitoring with one Addere

Proximal Flow Sensor

- Automatically calculates alveolar parameters, including real time Alveolar Driving Pressure
- Precise measurements, compatible with all mechanical ventilators



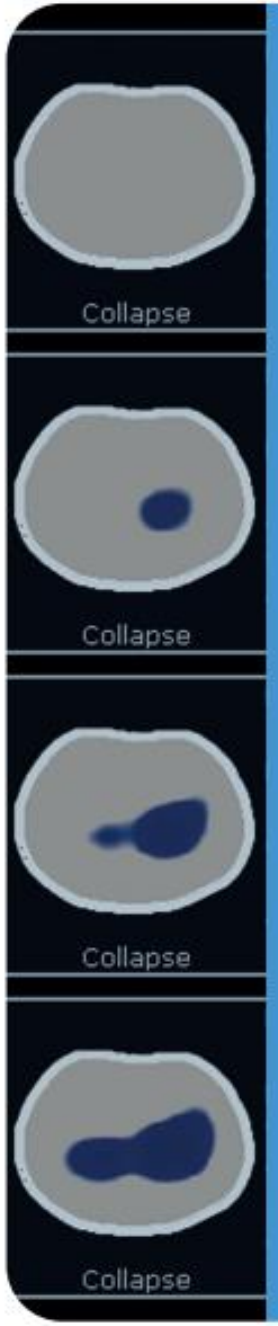
Belt is applied between the 4th and 5th intercostal space, providing visualization of a 15 cm slice, representing approximately 60% of the lung.


Module
Front Panel
Addere and Electrode Belt
Flow Sensor
Reference Cable
Power Supply

Hyperdistension (white)

Associated with higher risk of volumetrauma, hyperdistension is an area with high air levels and consequently lower compliance with lower gas exchange.

Collapse (dark blue)



Associated with higher risk of atelectrauma, collapse is an area with reduced or absence air levels, with consequently lower compliance and lower gas exchange.

Parameters

PEEP
17.1 cmH_2O
Hyperdistension
9 %
Collapse
0 %
Compliance
27 mL/cmH_2O

PEEP
15.2 cmH_2O
Hyperdistension
5 %
Collapse
6 %
Compliance
27 mL/cmH_2O

PEEP
13.1 cmH_2O
Hyperdistension
2 %
Collapse
12 %
Compliance
24 mL/cmH_2O

PEEP
11.1 cmH_2O
Hyperdistension
0 %
Collapse
20 %
Compliance
21 mL/cmH_2O

Values of PEEP hyperdistension, collapse and compliance for each step.

PEEP Titration Report

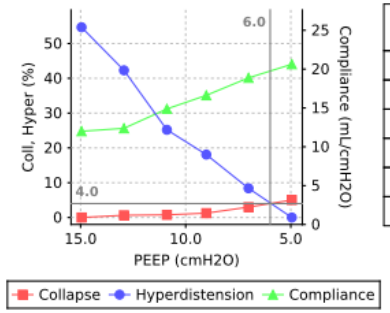
Patient ID:
Patient Name:
Date of Birth:
Hemiperimeter: 53.0 cm Belt Size: M Belt gap: 0.0 cm

Gender:

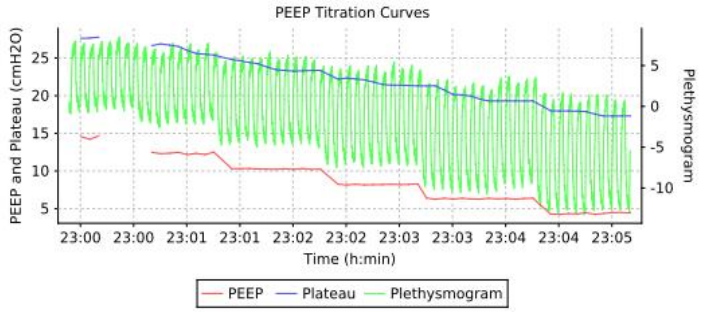
PEEP Titration Summary

Begin:
End:
Comment: ECMO SUPINE PEEP TITR

Countdown Time (s): 30
PEEP Decay Threshold (cmH2O): 2.0



PEEP (cmH_2O)	Compliance (mL/cmH_2O)	Hyperdist. (%)	Collapse (%)
15.0	12	55	0
12.9	12	42	1
10.9	15	25	1
9.0	17	18	1
7.0	19	8	3
5.0	21	0	5



Step Images

PEEP Step: 1

Hyperdistension Cumulative

PEEP: 15.0 cmH_2O
Hyperdistension: 55 %
Collapse: 0 %
Compliance: 12 mL/cmH_2O

PEEP Step: 2

Hyperdistension Cumulative

PEEP: 12.9 cmH_2O
Hyperdistension: 42 %
Collapse: 1 %
Compliance: 12 mL/cmH_2O

PEEP Step: 3

Hyperdistension Cumulative

PEEP: 10.9 cmH_2O
Hyperdistension: 25 %
Collapse: 1 %
Compliance: 15 mL/cmH_2O

Step Images (cont'd)

PEEP Step: 4

Hyperdistension Cumulative

PEEP: 9.0 cmH_2O
Hyperdistension: 18 %
Collapse: 1 %
Compliance: 17 mL/cmH_2O

PEEP Step: 5

Hyperdistension Cumulative

PEEP: 7.0 cmH_2O
Hyperdistension: 8 %
Collapse: 3 %
Compliance: 19 mL/cmH_2O

PEEP Step: 6

Hyperdistension Cumulative

PEEP: 5.0 cmH_2O
Hyperdistension: 0 %
Collapse: 5 %
Compliance: 21 mL/cmH_2O

#	Date	Description
1	2/10/24 22:59:53	PEEP titration start

Procedure of PEEP Titration

Patient A:

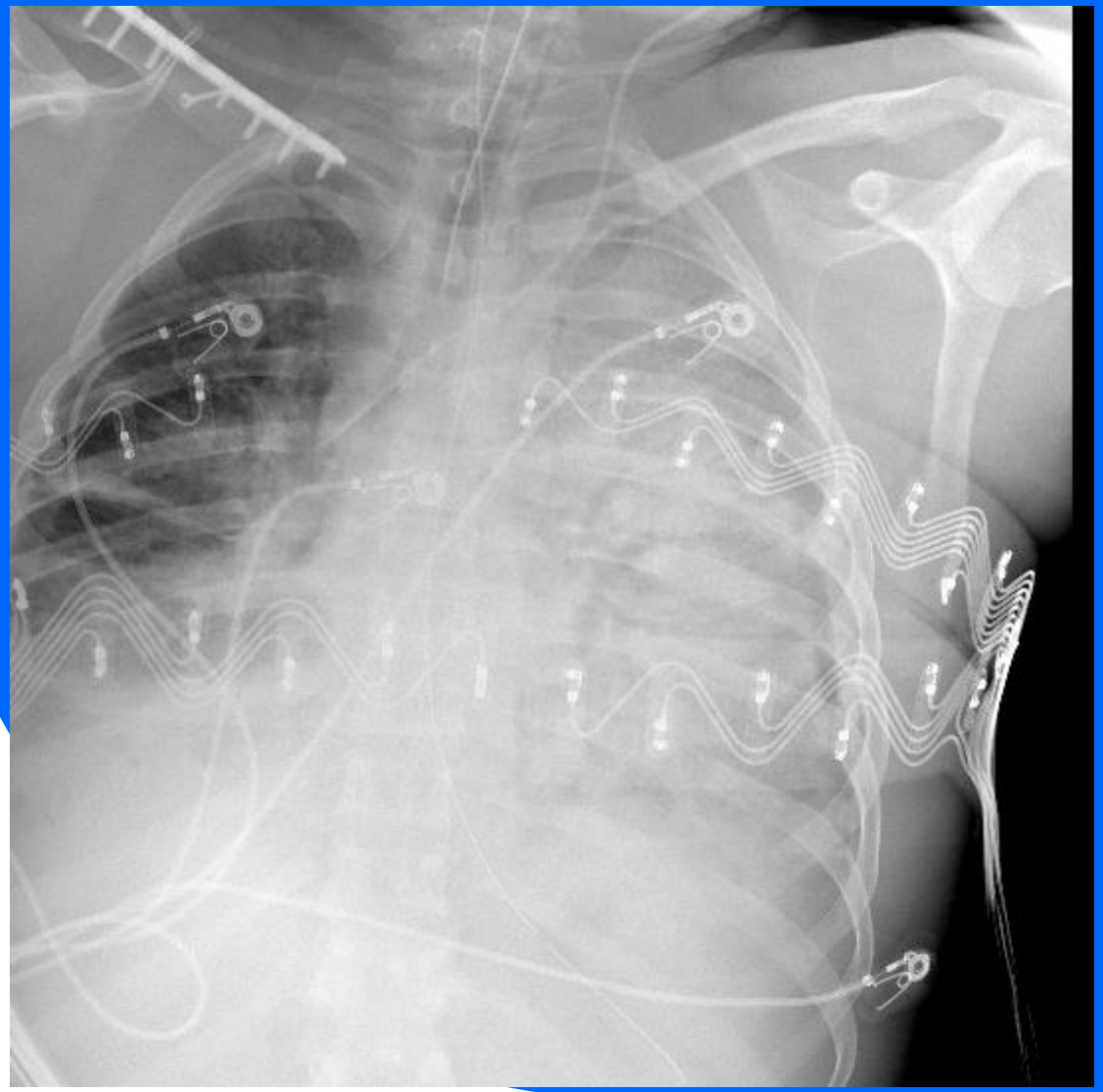
- EIT belts were applied, and measurements were taken during weaning on days 8, 9, and 10 on ECMO
  - We did use EIT prior to being placed on ECMO but we are going to focus on our PEEP titration for days 8-10
- The belts were used at this time and not earlier in the ECMO run as the patient was unstable in the first several days.
- At days 8-10, the patient was still being weaned from medical paralytic, but our team was unable to fully do so due to the patient becoming too agitated and having periods of desaturation.

Patient B:

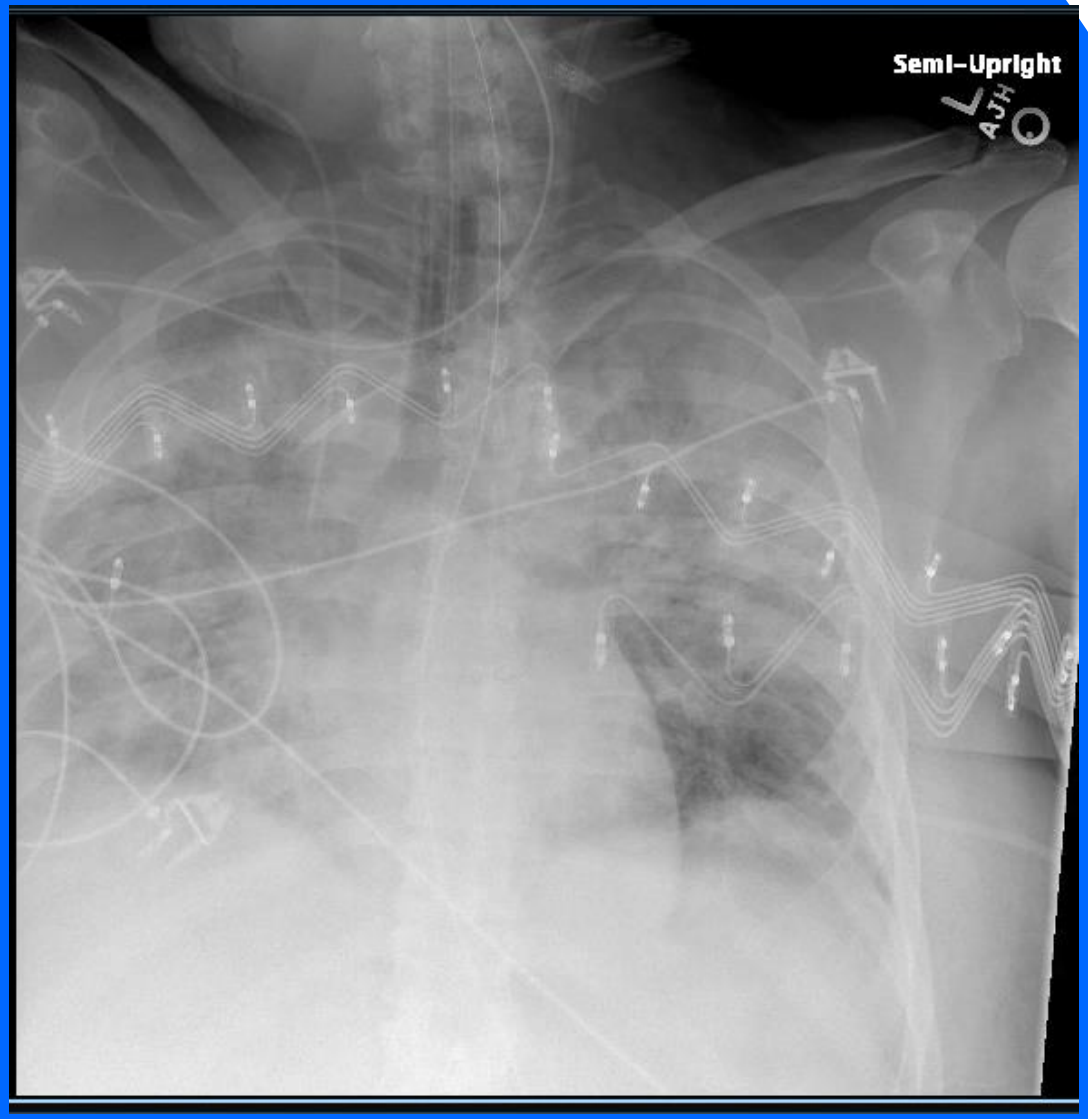
- EIT belts were used prior to being placed on ECMO and then on ECMO days 0-2 (3 days) to titrate PEEP as well as track changes post bronchoscopy and further titrate for optimal PEEP

Chest Xrays prior to ECMO

Patient A, prior to ECMO



Patient B, prior to ECMO



Patient activity

Patient A: Flu, MSSA, Aspergillosis (ARDS)

- EIT measurements indicated 'best' PEEP varied with different patient positions.
- PEEP derived by EIT was set on 8cmH2O in the supine position and set on 12cmH2O when right-side was up.
- Adjusting PEEP based on EIT data minimized hyperdistention and collapse and improved oxygenation with a **reduction in the fractional delivered oxygen (FdO2) on the ECMO circuit (75% to 50%), while maintaining oxygen saturation > 94%.**

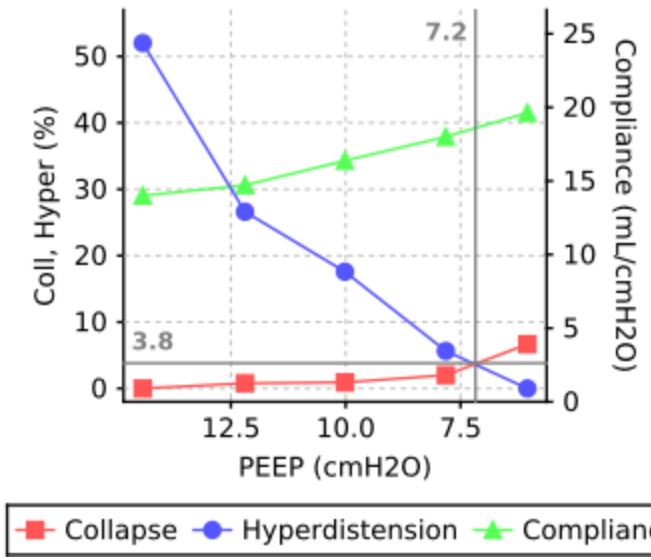
Patient B: Flu (ARDS/ARF)

- EIT was placed prior to ECMO to optimize PEEP; patient condition continued to worsen, ECMO was initiated.
- Post-ECMO cannulation, EIT was used to adjust PEEP and track ventilation distribution changes. Special attention was given to pinpoint areas of decreased ventilation distribution, using EIT distribution change mapping.
- **Post bronchoscopy, the patient demonstrated immediate improvements:**
  - PEEP reduced from 18cmH2O to 16 cmH2O
  - Increased lung compliance: 12 to 20 ml/cmH2O
  - Subsequent improvement in tidal volume: 136 ml to 237 ml
  - Resolving respiratory acidosis demonstrated by decreased PaCO2: 53.5 to 48 mmHg
  - Improved oxygenation: PaO2 72.9 to 105 mmHg with patient able to be successfully weaned off inhaled nitric oxide 6 hours post-bronchoscopy.

Patient A:

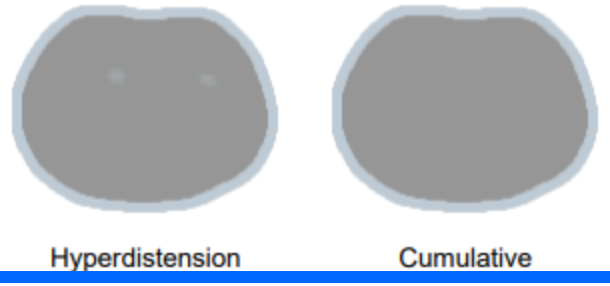
PEEP titration, individualized PEEP with rotation from Right to Supine (Left positioning PEEP at same setting for supine)

Day 8 of ECMO, Supine



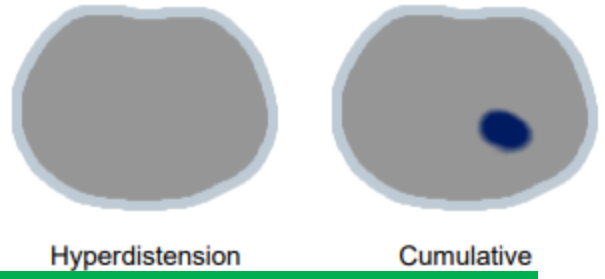
PEEP (cmH_2O)	Compliance (mL/cmH_2O)	Hyperdist. (%)	Collapse (%)
14.4	14	52	0
12.2	15	27	1
10.0	16	18	1
7.8	18	6	2
6.0	20	0	7

PEEP Step: 4



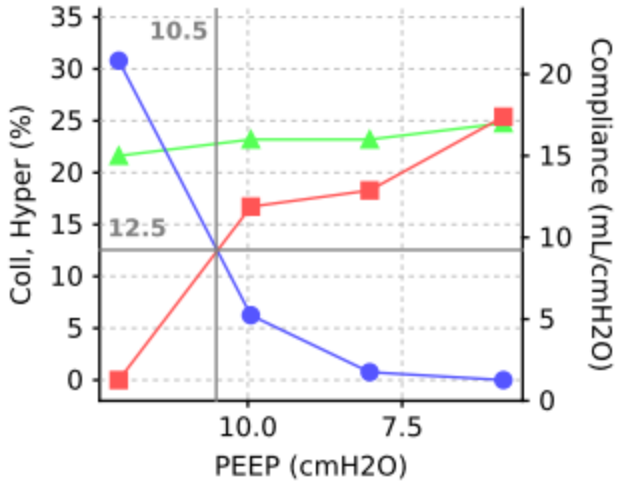
PEEP:	7.8 cmH_2O
Hyperdistension:	6 %
Collapse:	2 %
Compliance:	18 mL/cmH_2O

PEEP Step: 5



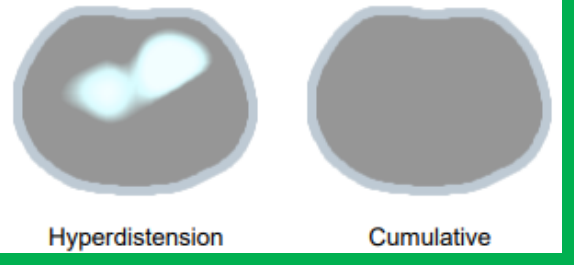
PEEP:	6.0 cmH_2O
Hyperdistension:	0 %
Collapse:	7 %
Compliance:	20 mL/cmH_2O

Day 9 of ECMO, Right side up/left down



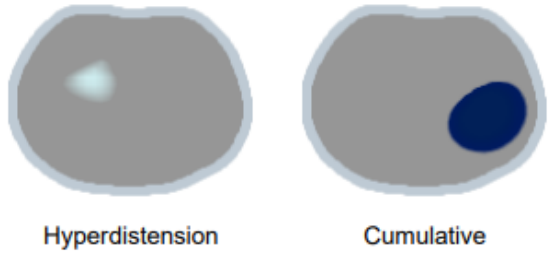
PEEP (cmH_2O)	Compliance (mL/cmH_2O)	Hyperdist. (%)	Collapse (%)
12.1	15	31	0
10.0	16	6	17
8.0	16	1	18
5.9	17	0	25

PEEP Step: 1



PEEP:	12.1 cmH_2O
Hyperdistension:	31 %
Collapse:	0 %
Compliance:	15 mL/cmH_2O

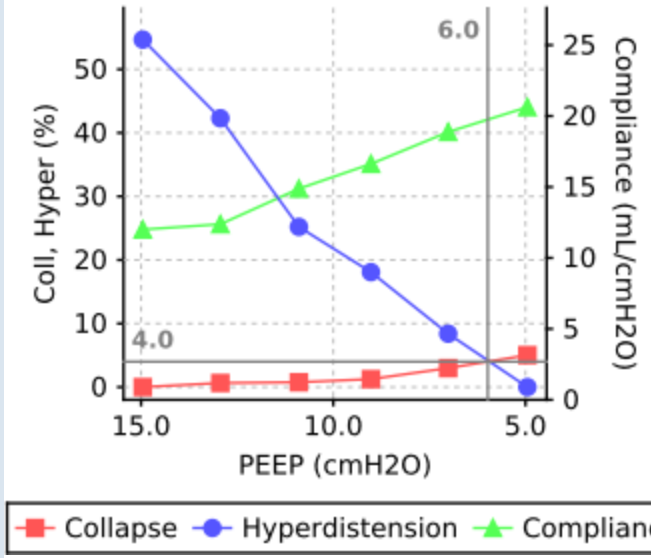
PEEP Step: 2



PEEP:	10.0 cmH_2O
Hyperdistension:	6 %
Collapse:	17 %
Compliance:	16 mL/cmH_2O

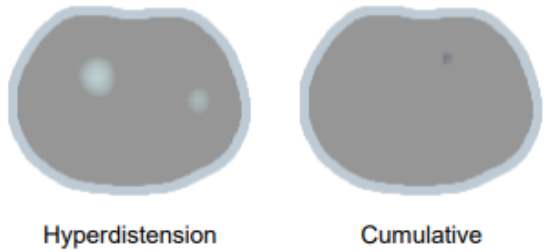
Patient A:
PEEP titration, individualized PEEP with rotation from Right to Supine (Left positioning at same setting for supine)

Day 9 of ECMO, Supine



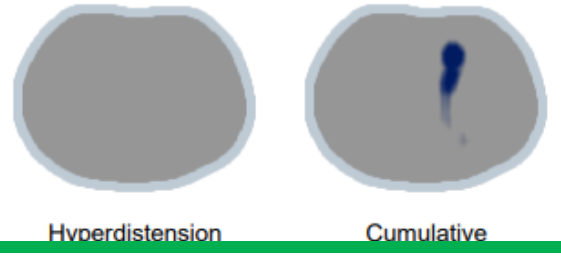
PEEP (cmH_2O)	Compliance (mL/cmH_2O)	Hyperdist. (%)	Collapse (%)
15.0	12	55	0
12.9	12	42	1
10.9	15	25	1
9.0	17	18	1
7.0	19	8	3
5.0	21	0	5

PEEP Step: 5



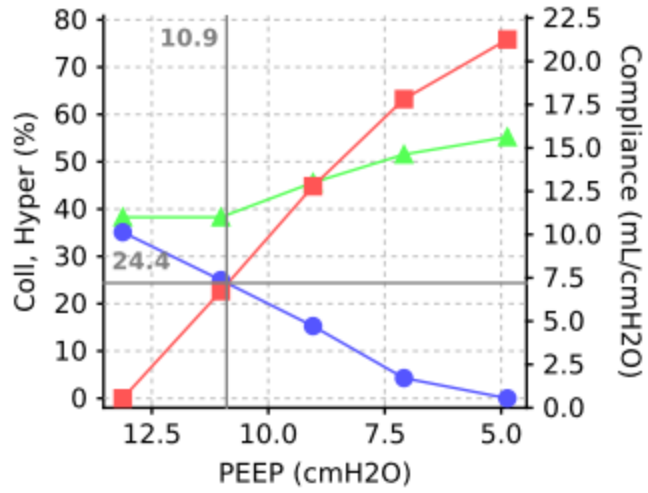
PEEP: 7.0 cmH_2O
Hyperdistension: 8 %
Collapse: 3 %
Compliance: 19 mL/cmH_2O

PEEP Step: 6



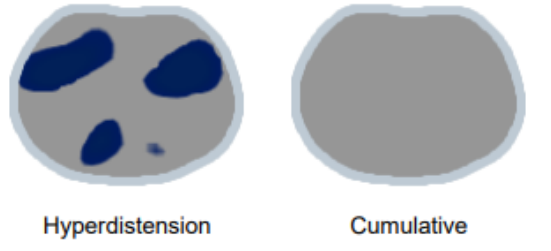
PEEP: 5.0 cmH_2O
Hyperdistension: 0 %
Collapse: 5 %
Compliance: 21 mL/cmH_2O

Day 10 of ECMO, Right side up/left down



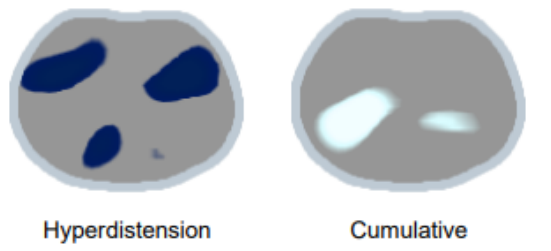
PEEP (cmH_2O)	Compliance (mL/cmH_2O)	Hyperdist. (%)	Collapse (%)
13.1	11	35	0
11.0	11	25	23
9.0	13	15	45
7.1	15	4	63
4.9	16	0	76

PEEP Step: 1



PEEP: 13.1 cmH_2O
Hyperdistension: 35 %
Collapse: 0 %
Compliance: 11 mL/cmH_2O

PEEP Step: 2

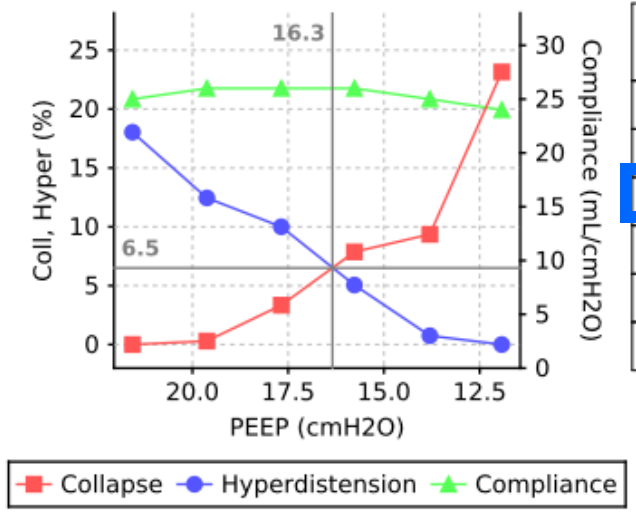


PEEP: 11.0 cmH_2O
Hyperdistension: 25 %
Collapse: 23 %
Compliance: 11 mL/cmH_2O

Patient B:
PEEP titration over series of days

Morning of being placed on ECMO

Countdown Time (s): 30
PEEP Decay Threshold (cmH2O): 2.0



PEEP (cmH_2O)	Compliance (mL/cmH_2O)	Hyperdist. (%)	Collapse (%)
21.6	25	18	0
19.6	26	12	0
17.7	26	10	3
15.8	26	5	8
13.8	25	1	9
11.9	24	0	23

PEEP Step: 3

PEEP: 17.7 cmH_2O
Hyperdistension: 10 %
Collapse: 3 %
Compliance: 26 mL/cmH_2O

PEEP Step: 4

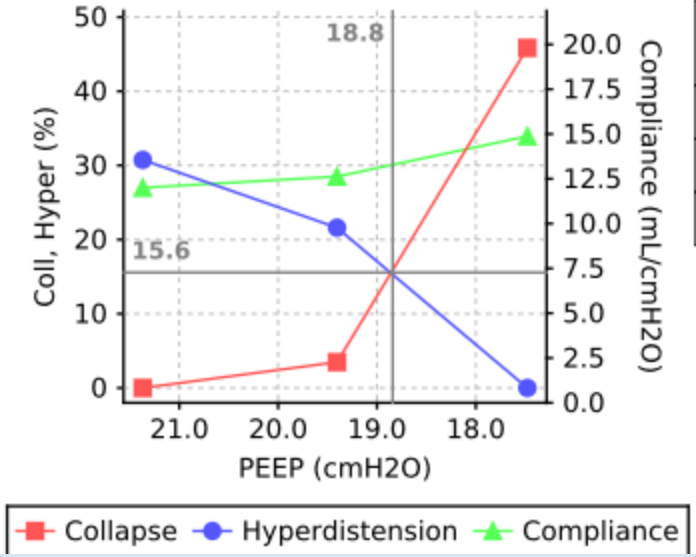
PEEP: 15.8 cmH_2O
Hyperdistension: 5 %
Collapse: 8 %
Compliance: 26 mL/cmH_2O

Selected for PEEP of 18 per graphics

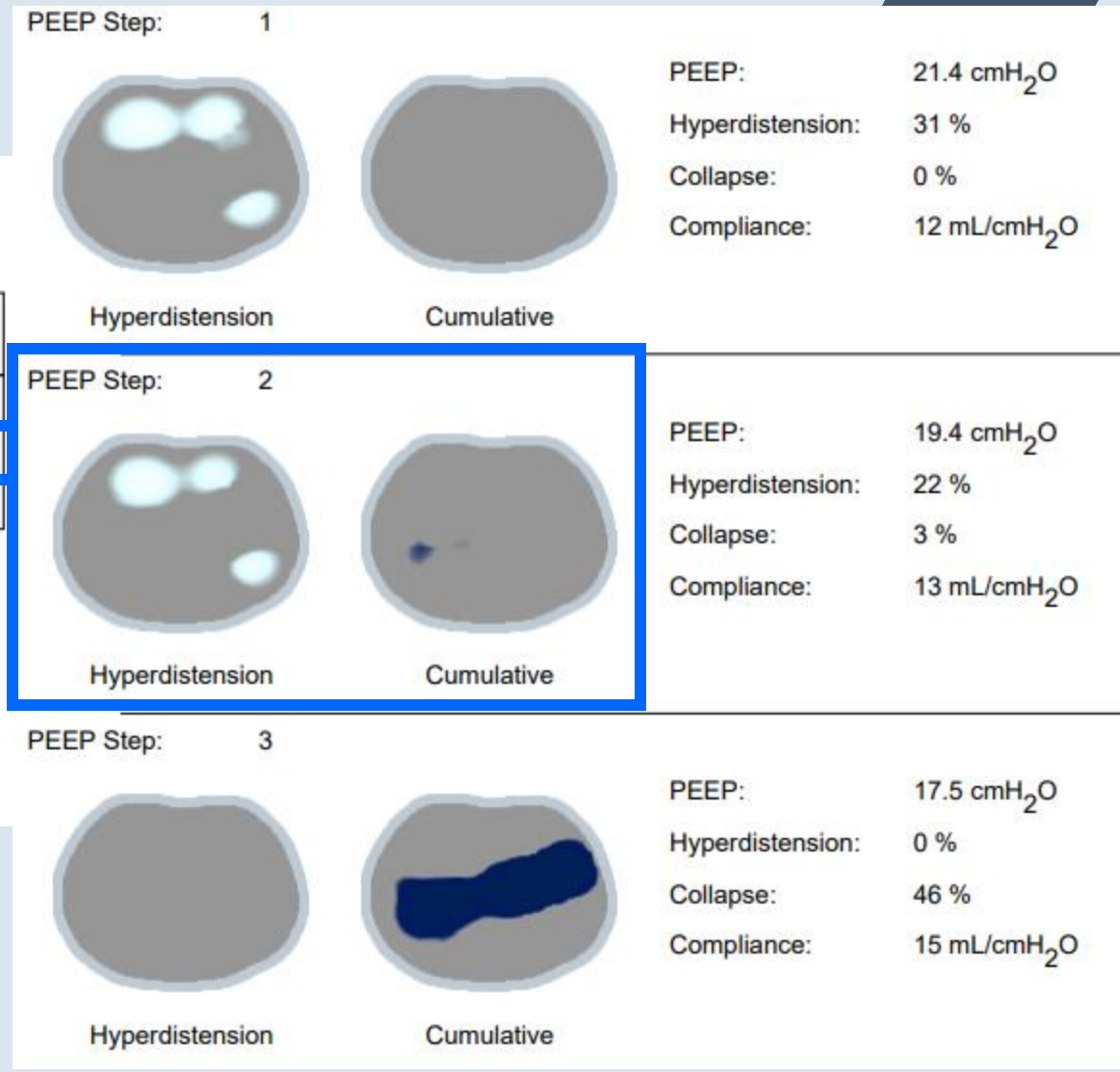
Patient B:
PEEP titration over series of days

Approximately 2.5 hours after being placed on ECMO

Countdown Time (s): 30
PEEP Decay Threshold (cmH2O): 2.0



PEEP (cmH_2O)	Compliance (mL/cmH_2O)	Hyperdist. (%)	Collapse (%)
21.4	12	31	0
19.4	13	22	3
17.5	15	0	46

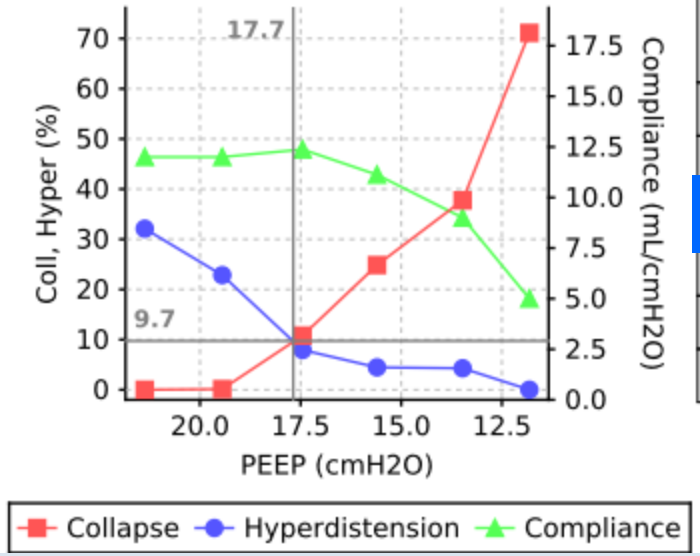


PEEP selected for 18cwp and vent set as such

Patient B:
PEEP titration over series of days

Approximately 16 hours after being placed on ECMO

Countdown Time (s): 30
PEEP Decay Threshold (cmH2O): 2.0

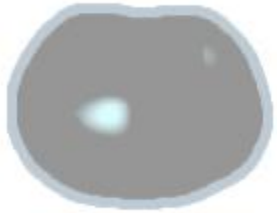


PEEP (cmH_2O)	Compliance (mL/cmH_2O)	Hyperdist. (%)	Collapse (%)
21.4	12	32	0
19.4	12	23	0
17.5	12	8	11
15.6	11	4	25
13.5	9	4	38
11.8	5	0	71

PEEP Step: 2

PEEP: 19.4 cmH_2O
Hyperdistension: 23 %
Collapse: 0 %
Compliance: 12 mL/cmH_2O

PEEP Step: 3



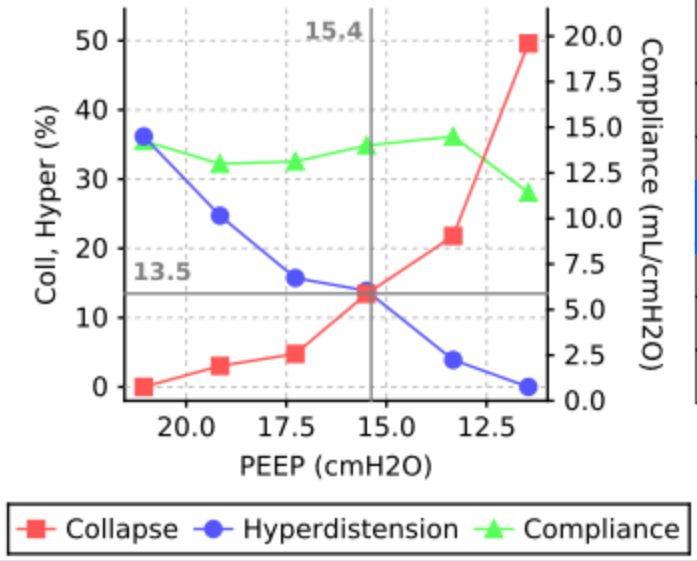
PEEP: 17.5 cmH_2O
Hyperdistension: 8 %
Collapse: 11 %
Compliance: 12 mL/cmH_2O

No change to PEEP with EIT or vent; remained at 18 cwp

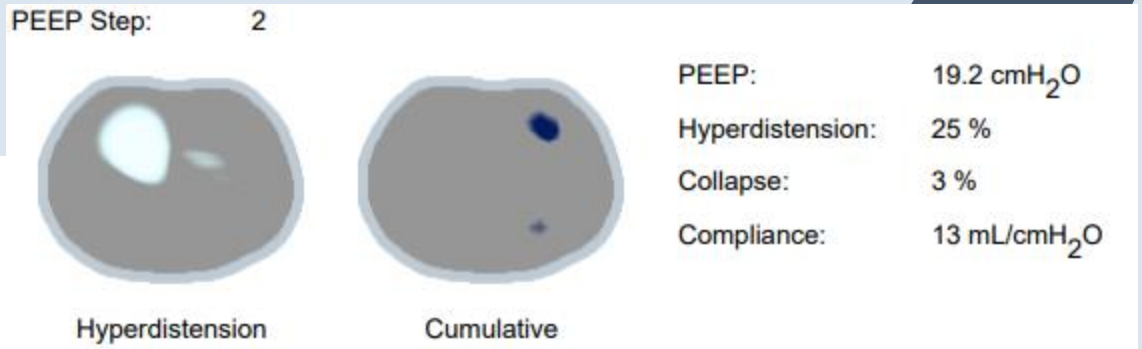
Patient B: PEEP titration over series of days

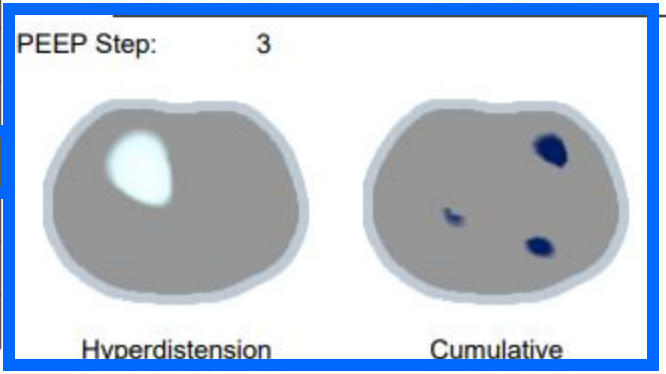
Approximately 24 hours after being placed on ECMO

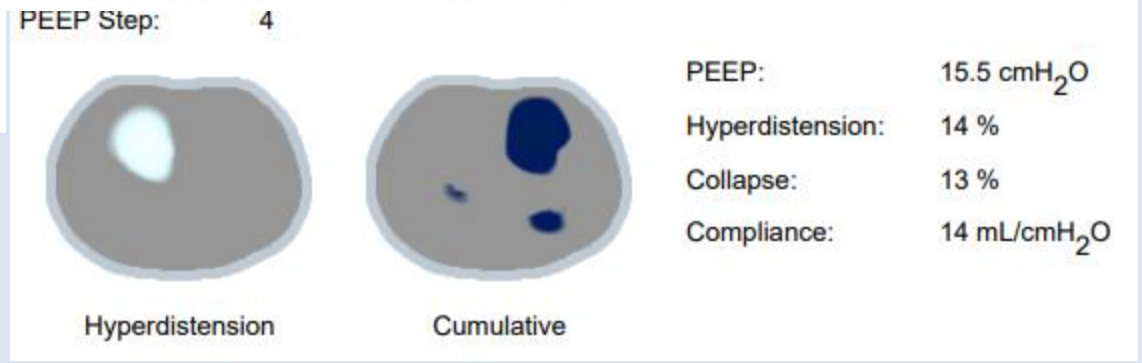
Countdown Time (s): 30
PEEP Decay Threshold (cmH2O): 2.0



PEEP (cmH_2O)	Compliance (mL/cmH_2O)	Hyperdist. (%)	Collapse (%)
21.1	14	36	0
19.2	13	25	3
17.3	13	16	5
15.5	14	14	13
13.3	14	4	22
11.5	11	0	50





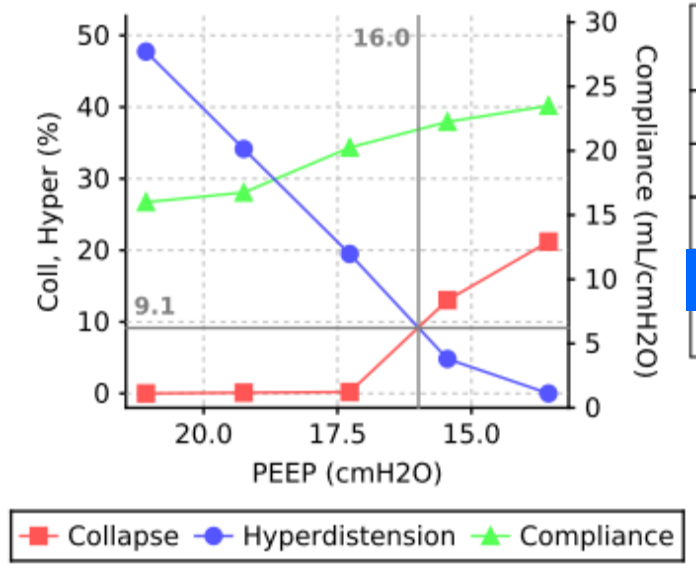


No change to PEEP with EIT or vent; remained at 18 cmH2O; note that calculation shows “15.4 cmH2O”, however, closer inspection of graphics would suggest keeping 18 cmH2O

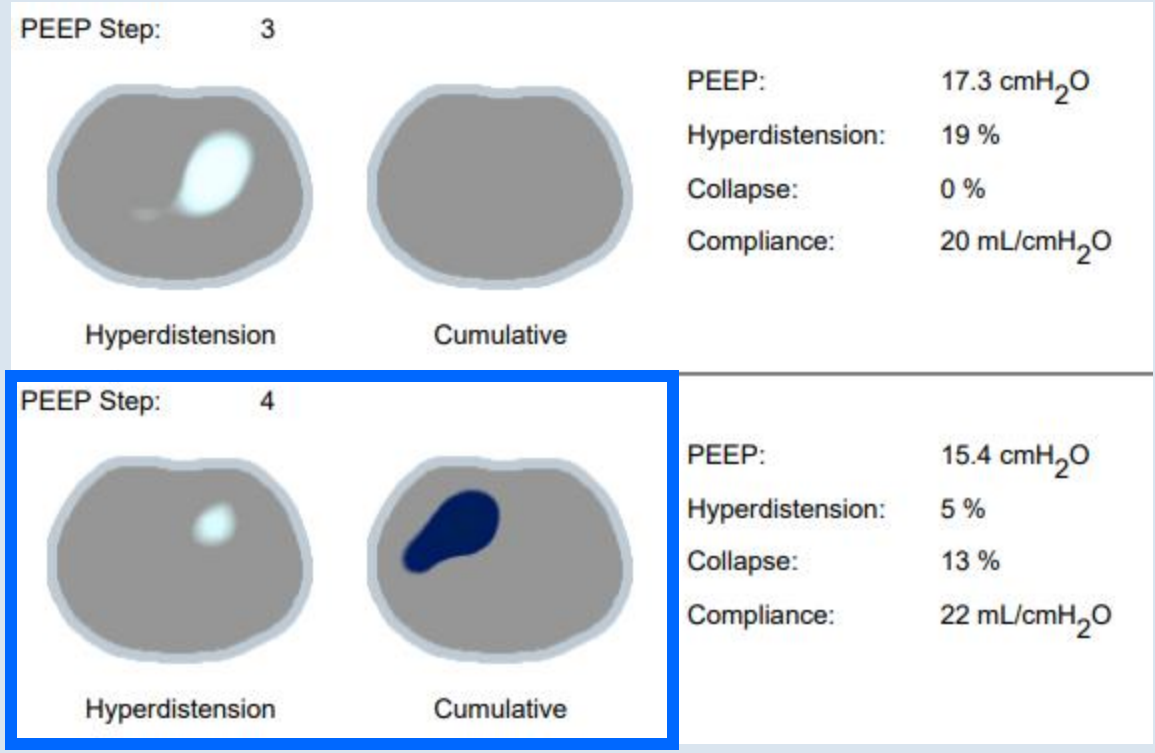
Patient B: PEEP titration over series of days

Approximately 46 hours after being placed on ECMO AND 3 hours after bronchoscopy

Countdown Time (s): 30
PEEP Decay Threshold (cmH2O): 2.0



PEEP (cmH_2O)	Compliance (mL/cmH_2O)	Hyperdist. (%)	Collapse (%)
21.1	16	48	0
19.2	17	34	0
17.3	20	19	0
15.4	22	5	13
13.6	24	0	21

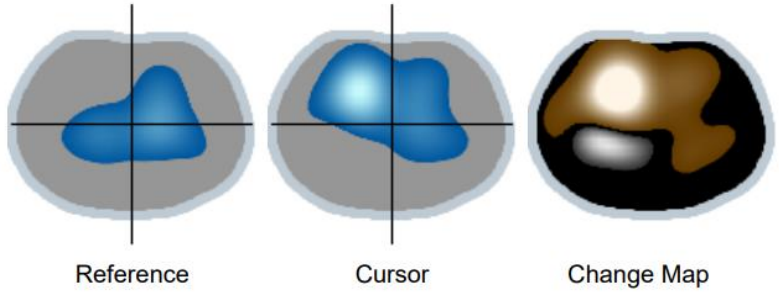


Per EIT calculation and graphics, we weaned to 16 cmH2O on ventilator and patient tolerated well

Pt was also able to wean from Inhaled nitric oxide after bronchoscopy and reduction of PEEP 2 hours later

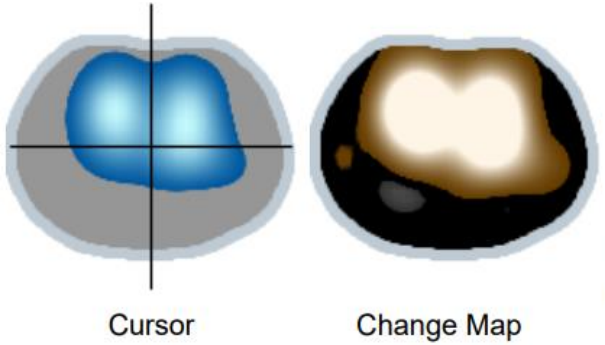
Patient B: Pre/Post Bronch, 2 hrs post, 3 hours post

Distribution Change Map



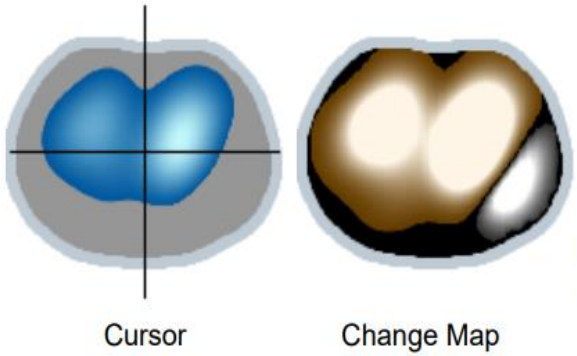
Pre/Post 10 mins

	Reference	Cursor
Date:		
Time:		
A/P (%):	39 % / 61 %	71 % / 29 %
R/L (%):	32 % / 68 %	69 % / 31 %
$P_{Driving}$ (cmH_2O):	--	16.1
C_{RS} (mL/cmH_2O):	--	7
TVz:	0.8 (100%)	2.5 (291%)
VT (mL):	40	136
PEEP (cmH_2O):	17.5	17.4
RR (bpm):	41	12



Pre/Post 2 hours

	Reference	Cursor
Date:		
Time:		
A/P (%):	39 % / 61 %	67 % / 33 %
R/L (%):	32 % / 68 %	42 % / 58 %
$P_{Driving}$ (cmH_2O):	--	12.4
C_{RS} (mL/cmH_2O):	--	17
TVz:	0.8 (100%)	5.4 (636%)
VT (mL):	40	214
PEEP (cmH_2O):	17.5	17.5
RR (bpm):	41	12



Pre/Post 3 hours

	Reference	Cursor
Date:		
Time:		
A/P (%):	39 % / 61 %	70 % / 30 %
R/L (%):	32 % / 68 %	46 % / 54 %
$P_{Driving}$ (cmH_2O):	--	12.4
C_{RS} (mL/cmH_2O):	--	21
TVz:	0.8 (100%)	7.4 (878%)
VT (mL):	40	237
PEEP (cmH_2O):	17.5	17.4
RR (bpm):	41	12

Patient A and B

- In both patient cases, we were able to:
  - Individually select ventilator settings based on best compliance with least amount of hyperdistention and collapse
  - Wean FdO2 and/or Inhaled Nitric Oxide significantly
  - Maintain SpO2 goal levels, even with turning patient to provide appropriate cares to prevent pressure injury
  - Continue to monitor ventilation distribution improvements over series of days, beyond Vt exhaled on the ventilator

Research plan

- Collect data to be used for case studies with patients requiring VV-ECMO (veno-venous ECMO) eligible for EIT belt that will be used to optimize ventilator settings and guide bronchoscopy intervention.
- Early results indicating improved ventilation distribution using EIT guided PEEP, particularly after bronchoscopy.
- We plan to use the EIT belt for real-time monitoring before, during, and after bronchoscopy, hypothesizing that it will help detect ventilatory changes and allow for timely interventions before clinical deterioration is noted.

Conclusion

- EIT can be a safe and effective tool used in conjunction with ECMO to reduce ventilator settings by achieving the goal of reducing hyperdistention and collapse while maintaining ventilation at the best compliance.

- EIT also can offer the capability of determining different levels of PEEP in patients who may be presenting with differential lung disease, with portions of lung more and less compliant than other sections of lung, dependent on position or time during an ECMO run.

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Thank you

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