

# Mechanical ventilation (Hands-on)

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Director of ICUs

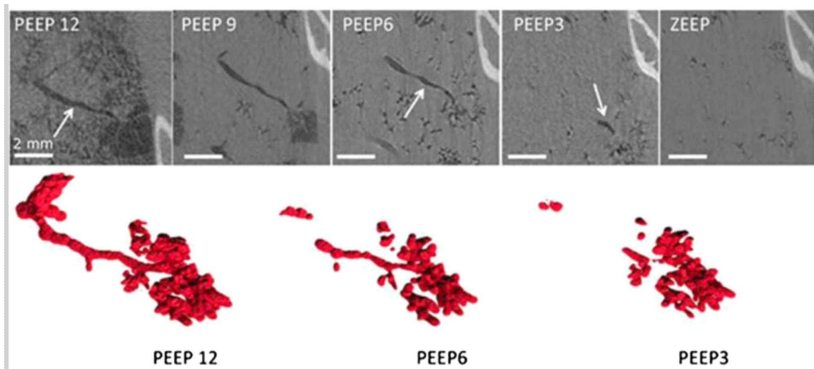
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Hallym University Sacred Heart Hospital

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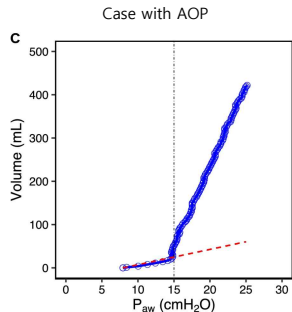
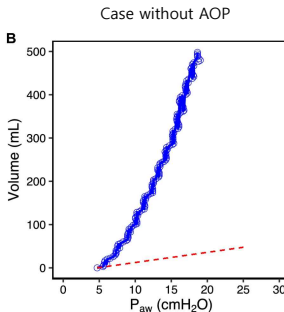
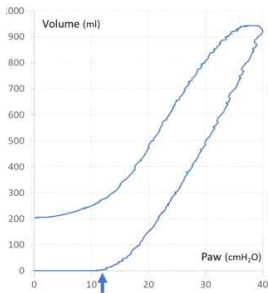
- Airway opening pressure (AOP)
- Respiratory time constant
- Stress index (SI)
- $P_{0.1}$
- Pressure muscle index (PMI)
- $P_{occ}$
- Recruitment to inflation ratio (R/I ratio)
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# Airway opening pressure

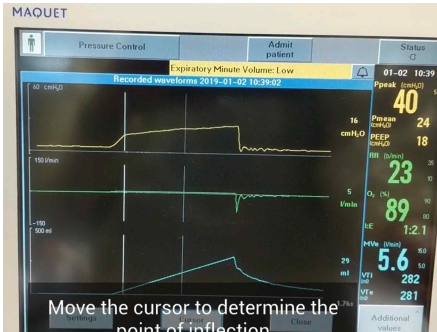


# Airway opening pressure

ARDS, obesity, atelectasis, cardiac arrest



# Airway opening pressure



<https://rtmaven.com/>



SIMV (VC), RR 5, Vt 6 cc/kg. Flow rate 5L/min, PEEP 5

# Respiratory time constant

“Length of time required for the lungs to deflate (or inflate) to a certain amount of their volume”

$$RC_{exp} = \text{Resistance (cm H}_2\text{O/L/sec)} \times \text{Compliance (L/cm H}_2\text{O)}$$

$P_{peak} - P_{plat}$

Flow

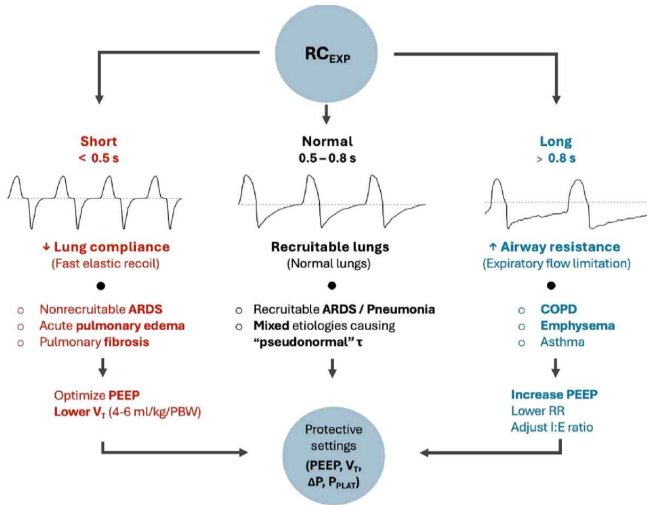
Normal range 0.5 – 0.7

1T → **63% exhaled**

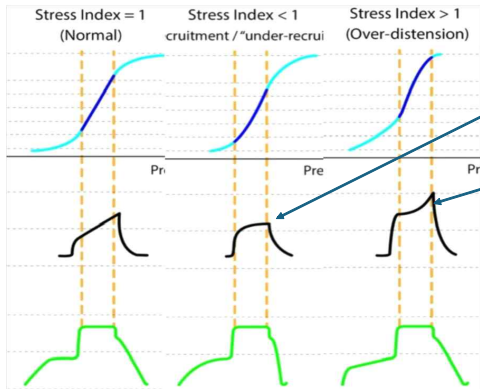
3T → **95% exhaled**

5T → **99% exhaled**





# Stress index (SI)

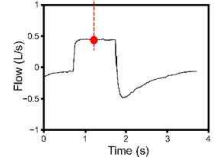
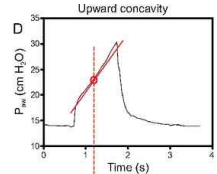
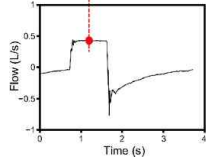
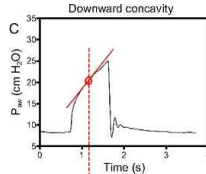
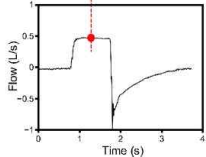
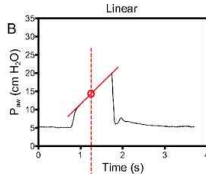
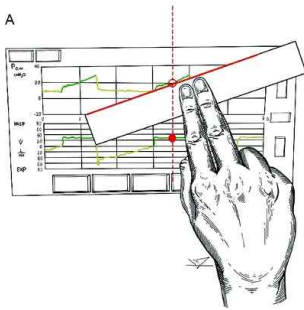


High compliance  
-> increase PEEP

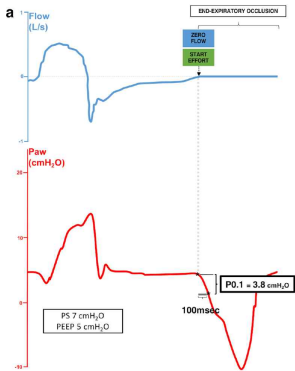
Low compliance  
-> decrease PEEP

# Stress index (SI)

VCV mode with constant flow



# Airway occlusion pressure at 100 ms ( $P_{0.1}$ )

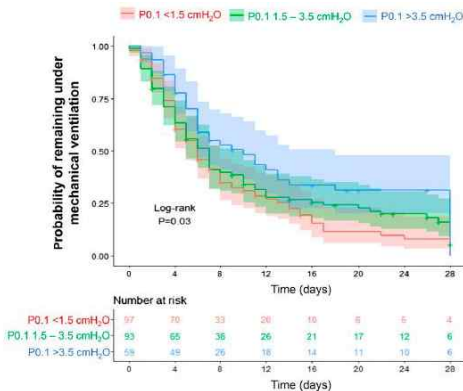


Central respiratory drive  
(irrespective of consciousness)

Well correlated with WOB and PTP

- Healthy, 0.5 – 1.5 cmH<sub>2</sub>O
- COPD, 2.5 - 5.0 cmH<sub>2</sub>O
- ARDS, 3.0 – 6.0 cmH<sub>2</sub>O
- MV weaning, 1.0 – 13.0 cmH<sub>2</sub>O

# Airway occlusion pressure at 100 ms ( $P_{0.1}$ )

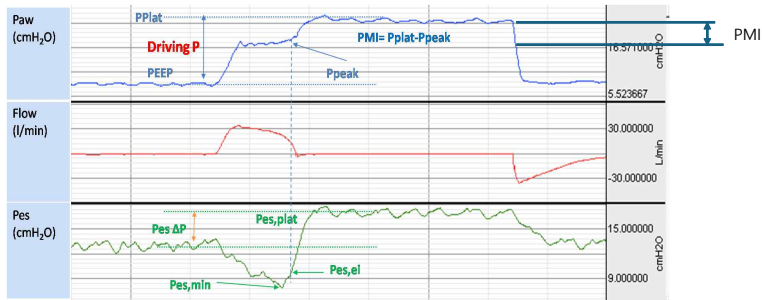


260 patients in 10 ICUs

**High  $P_{0.1}$**

Dyspnea  
Mortality  
Duration of MV

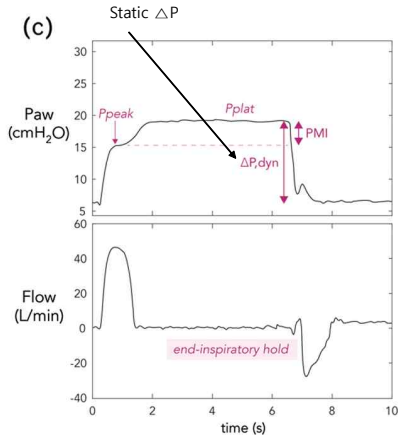
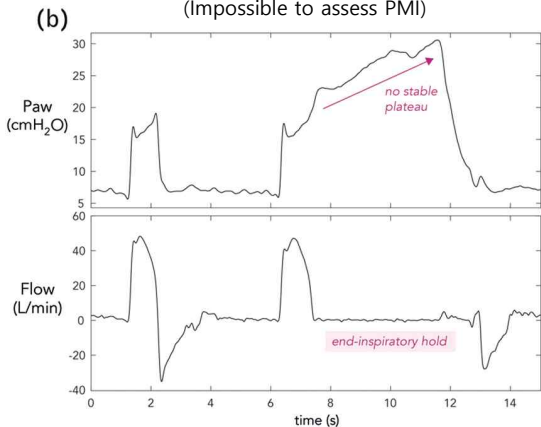
# Pressure muscle index (PMI)



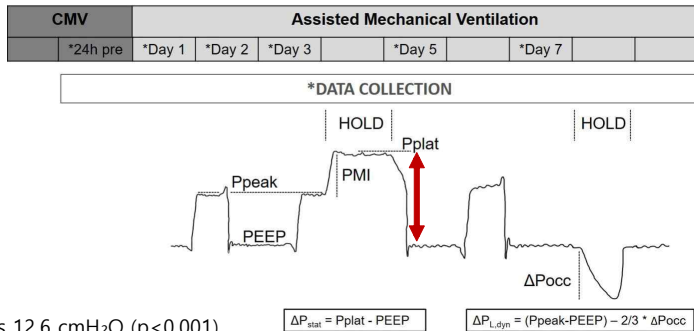
*"Driving pressure can be higher than set PS level during PSV"*

- <https://coemv.blog/can-we-measure-plateau-pressure-during-pressure-support-and-what-does-it-indicate/>
- Forti et al. AM J RESPIR CRIT CARE MED 1997;156:1210-1216

A sign of high inspiratory effort  
(Impossible to assess PMI)



## Increased Driving Pressure During Assisted Ventilation for Hypoxemic Respiratory Failure Is Associated with Lower ICU Survival: [The ICEBERG Study](#)



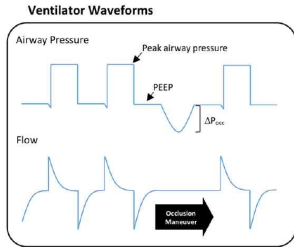
$\Delta P_{stat}$  (DP) : **11.3** vs 12.6 cmH<sub>2</sub>O (p<0.001)

$\Delta P_{L,dyn}$  ( $P_{trans}$ ): **15.7** vs 18.7 cmH<sub>2</sub>O (p<0.001)

*“Quasi-static DP may be a valuable tool during spontaneous assisted breathing”*

# Airway occlusion pressure ( $P_{occ}$ )

$P_{nadir} - PEEP$   
(nl, 7-13 cmH<sub>2</sub>O)



Predicted  $P_{mus} = -3/4 \times \Delta P_{occ}$

Predicted  $\Delta P_L = (\text{Peak airway pressure} - PEEP) - 2/3 \times \Delta P_{occ}$

**Note:**  $\Delta P_{occ}$  is always  $\leq 0$  cm H<sub>2</sub>O (the magnitude of decrease in airway pressure from inspiratory effort during the occlusion)

Measure  $\Delta P_{occ}$  every 4-8 hours  
(3 single-breath end-expiratory occlusions)

Estimate  $P_{mus}$   
If  $\Delta P_{occ} < 0$  cm H<sub>2</sub>O, estimate  $\Delta P_L$

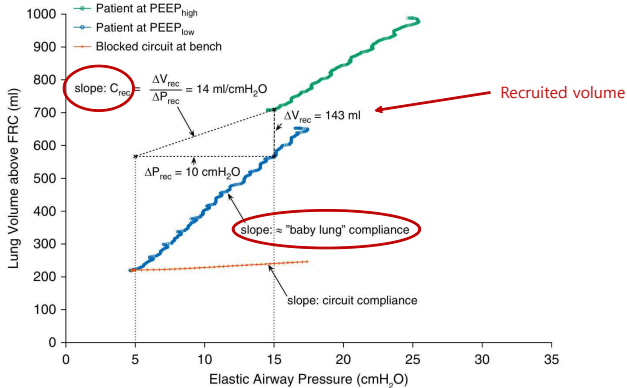
Predicted  $P_{mus} > 13-15$  cm H<sub>2</sub>O  
OR  
Predicted  $\Delta P_L \geq 16-17$  cm H<sub>2</sub>O

Target achieved

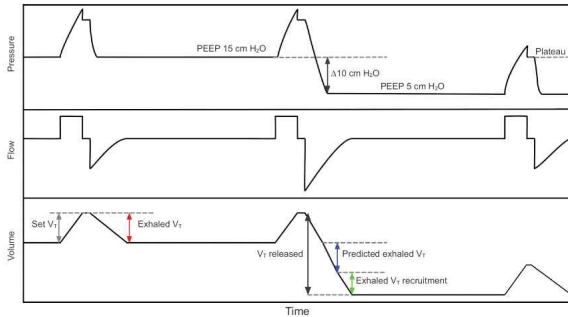
Yes

Consider  $P_{es}$  monitoring to guide clinical management  
OR  
Consider modifying sedation and ventilation to achieve predicted  $P_{mus}$  and  $\Delta P_L$  within acceptable limits

# Recruitment to inflation (R/I) ratio



# Recruitment to inflation (R/I) ratio



$$C_{rec} = \frac{\text{recruited volume}}{PEEP_{high} - PEEP_{low}}$$

**Compliance** of recruited lung

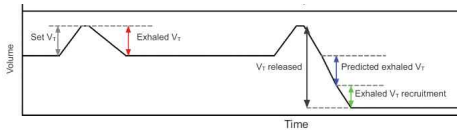
$$\frac{R}{I} = \frac{C_{rec}}{C_{rs \text{ at low PEEP}}}$$

**Compliance** of baby lung

# Recruitment to inflation (R/I) ratio

1. Deep sedation (NMBAs), VCV mode, RR 5-8, short inspiratory pause.
2. Ventilation for 10 – 15 min with PEEP 15 (high PEEP)
3. Sudden change of PEEP: 15 (high)  $\rightarrow$  5 (low)

$$\mathbf{Vrec} = \text{Released vol.} - \text{Exhaled } V_t \\ - \text{Predicted } V_t \text{ (inflated vol.)}$$



$$\mathbf{Crec} = Vrec / (PEEP_{\text{high}} - \text{low } PEEP_{\text{low}}) = Vrec / 10$$

$$\mathbf{Crs \text{ at } PEEP_{\text{low}}} = Vt \text{ at } PEEP_{\text{low}} / (P_{\text{plat}} - PEEP_{\text{low}}) \rightarrow \text{Baby lung } \text{의 } \text{compliance}$$

$$\mathbf{\text{Predicted } Vt \text{ (inflated vol)}} = Crs \text{ at } PEEP_{\text{low}} \times (PEEP_{\text{high}} - PEEP_{\text{low}}) = Crs \text{ at } PEEP_{\text{low}} \times 10$$



# R/I calculation

Vt = exhaled vol.

PEEP<sub>high</sub> = 15

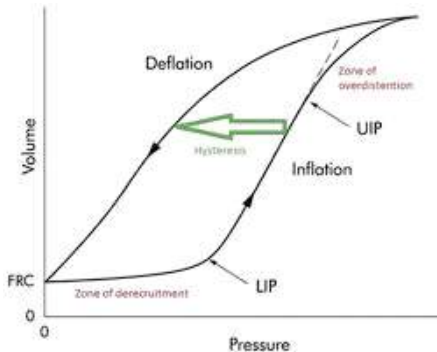
PEEP<sub>low</sub> = 5 (or AOP)

Predicted Vt = inflated vol.

C<sub>rs</sub> at PEEP<sub>low</sub> = baby lung C<sub>rs</sub>

- Vt at PEEP<sub>high</sub> =
  - Released volume (from PEEP<sub>high</sub> to PEEP<sub>low</sub>) =
  - Vt at PEEP<sub>low</sub> =
  - P<sub>plat</sub> at PEEP<sub>low</sub> =
  - **C<sub>rs</sub> at PEEP<sub>low</sub>** = Vt at PEEP<sub>low</sub> / (P<sub>plat</sub> - PEEP<sub>low</sub>) =
  - **Predicted Vt** = C<sub>rs</sub> at PEEP<sub>low</sub> X (PEEP<sub>high</sub> - PEEP<sub>low</sub>) =
  - **V<sub>rec</sub>** = Released Vol. - Vt at PEEP<sub>high</sub> - predicted Vt at PEEP<sub>low</sub> =
  - **C<sub>rec</sub>** = V<sub>rec</sub> / (PEEP<sub>high</sub> - PEEP<sub>low</sub>) = V<sub>rec</sub> / 10 =
- R/I = C<sub>rec</sub> / C<sub>rs</sub> at PEEP<sub>low</sub> =**

# Tidal recruitment in P-V curve



## Definition

Volume which is open and closed during respiration  
Correlated with hysteresis in P-V curve

## High tidal recruitment (increased hysteresis)

- ⇒ Risk of VILI (atelectrauma)
- ⇒ May need a higher PEEP
- ⇒ But, it does not mean high recruitability

## Signals suggesting positive effects of increasing PEEP

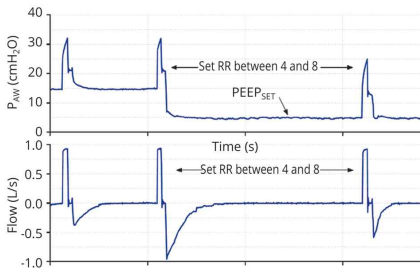
- ↓ **Hysteresis** in P-V curves
- ↓ or **disappearance of LIP** in P-V curves
- **A more linearity** of P-V curves
- ↓ **Dead space**
- ↓ **Driving pressure**
- ↑ **Oxygenation and compliance**
- **Stable hemodynamics**

*"However, improvement in oxygenation or compliance alone is unreliable."*

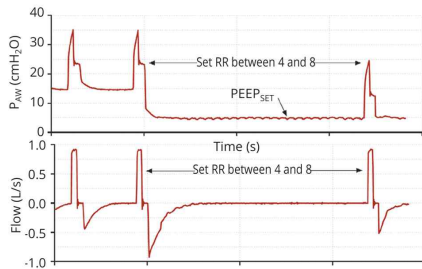
*Consider shunt and tidal recruitment, respectively*

Thank you

High recruitability, R/I = 1.05



Low recruitability, R/I = 0.25



A

B