Beth Israel Deaconess Medical Center

A teaching hospital of Harvard Medical School

Mechanical Ventilation Guided by Esophageal Pressure in Acute Lung Injury *

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* n engl j med 359;20 november 13, 2008

Pleural Pressure Measurement
The Problem ~

- Lung over-distension causes ALI.
- Repetitive collapse/re-inflation causes ALI.
- Atelectasis may cause organ failure.

The ARDSnet low tidal volume ventilation study showed a mortality benefit using:

  - Low Vt 6 ml/kg (4 – 8)
  - Pplat $\leq$ 30 cm H_2O (?)
- PEEP and FiO_2 set to keep PaO_2 between 55 and 80 mmHg but optimal PEEP was not addressed.
- Can these strategies be improved?

Pleural Pressure Measurement
High vs Low PEEP Trials

Trial	Year	Low PEEP Day 1 - 3	High PEEP Day 1 - 3	High PEEP Benefit	Comment
Amato	1998 NEJM			Yes	PEEP to LIP
ALVEOLI	2004 NEJM	8.9 - 8.5	14.7 – 12.9	No	No early separation of PEEPs
ARIES	2006 CCM	9.0 – 8.7	14.1 – 11.2	Yes	PEEP to LIP
LOVS	2008 JAMA	10.1 – 8.8	15.6 – 11.8	No	Hi PEEP allowed Pplat $\leq$ 40
EXPRESS	2008 JAMA	7.1 – 6.7	14.6 – 13.4	Mixed	PEEP $\uparrow$'d till Pplat = 28 - 30

Pleural Pressure Measurement Hypothesis

- Depending on the chest wall contribution to respiratory mechanics, a given PEEP level or plateau pressure may be adequate for one patient but potentially injurious for another.

- This may explain varying results in clinical trials.

Pleural Pressure Measurement
The Clinical Problem

- During MV, the pressure applied to the lung itself is unknown, but is often assumed to be the same as ventilator pressures.

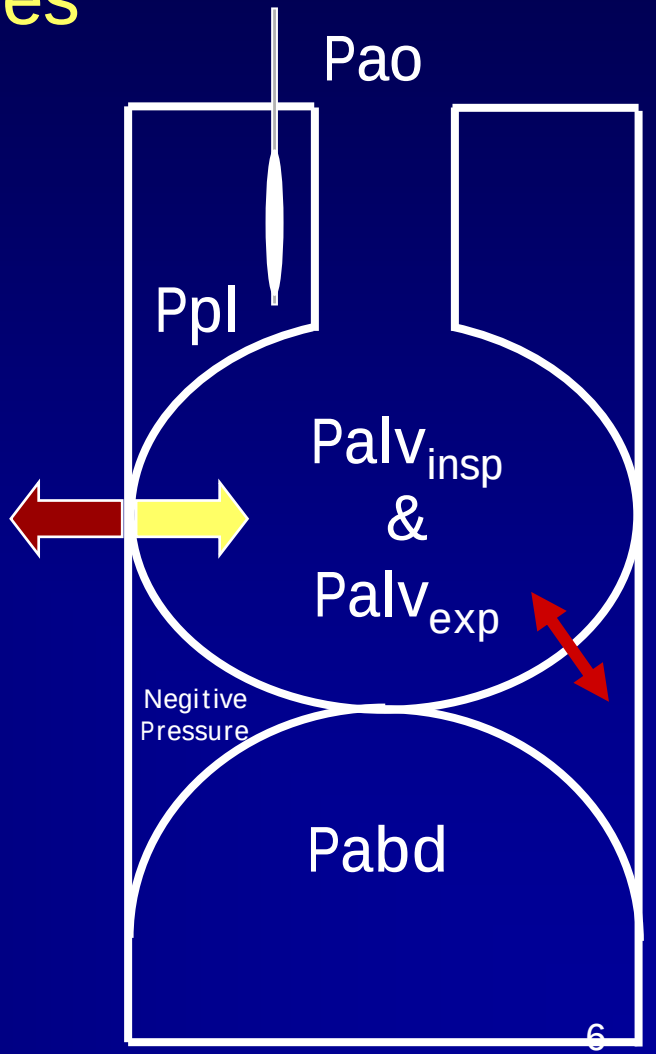
- In some patients, the chest wall contributes a large part of the transrespiratory pressure, making the above assumption false.

- Knowing pleural pressure could allow calculation of transpulmonary pressure to permit ventilation with pressures appropriate to the lungs.

Pleural Pressure Measurement

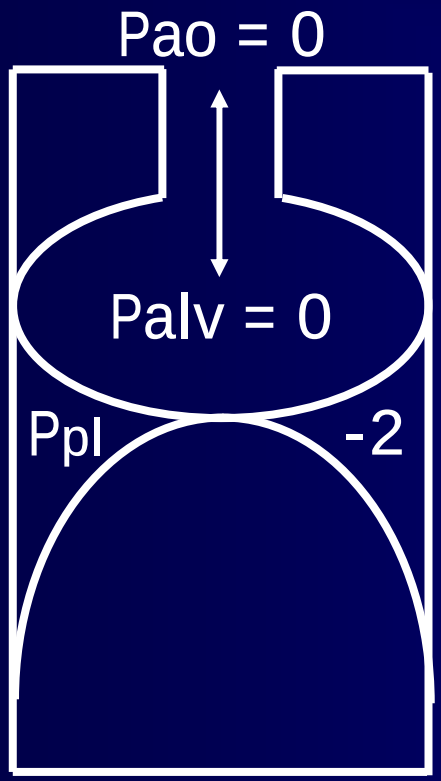
Thoracic/Abdominal Pressures

- $Palv_{insp}$ = Pplat
- $Palv_{exp}$ = $PEEP_{tot}$ [$PEEP_{app}$ + $PEEP_{intr}$]
- Ppl = Pes
- Pabd = Bladder Pr.
- Ptp = Palv - Ppl

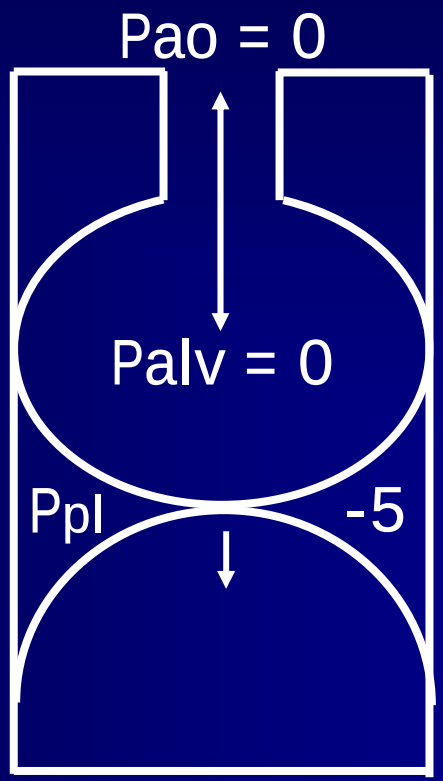


Pleural Pressure Measurement

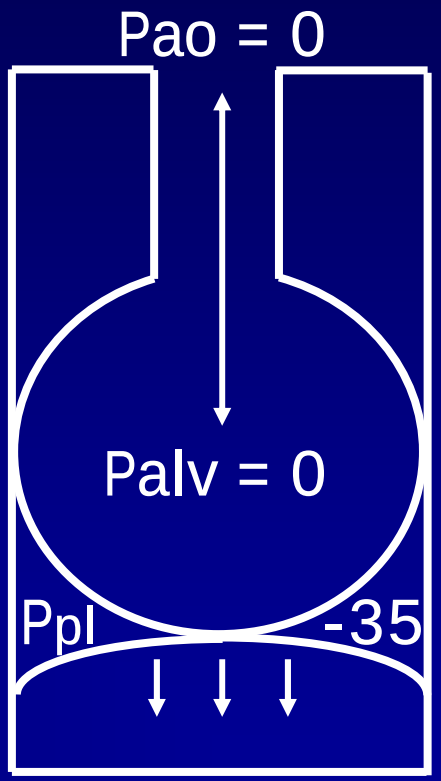
Normal Pl and Ppl Relationship (Palv - Ppl = Ptp)



0 - (-2) = 2
Resting FRC

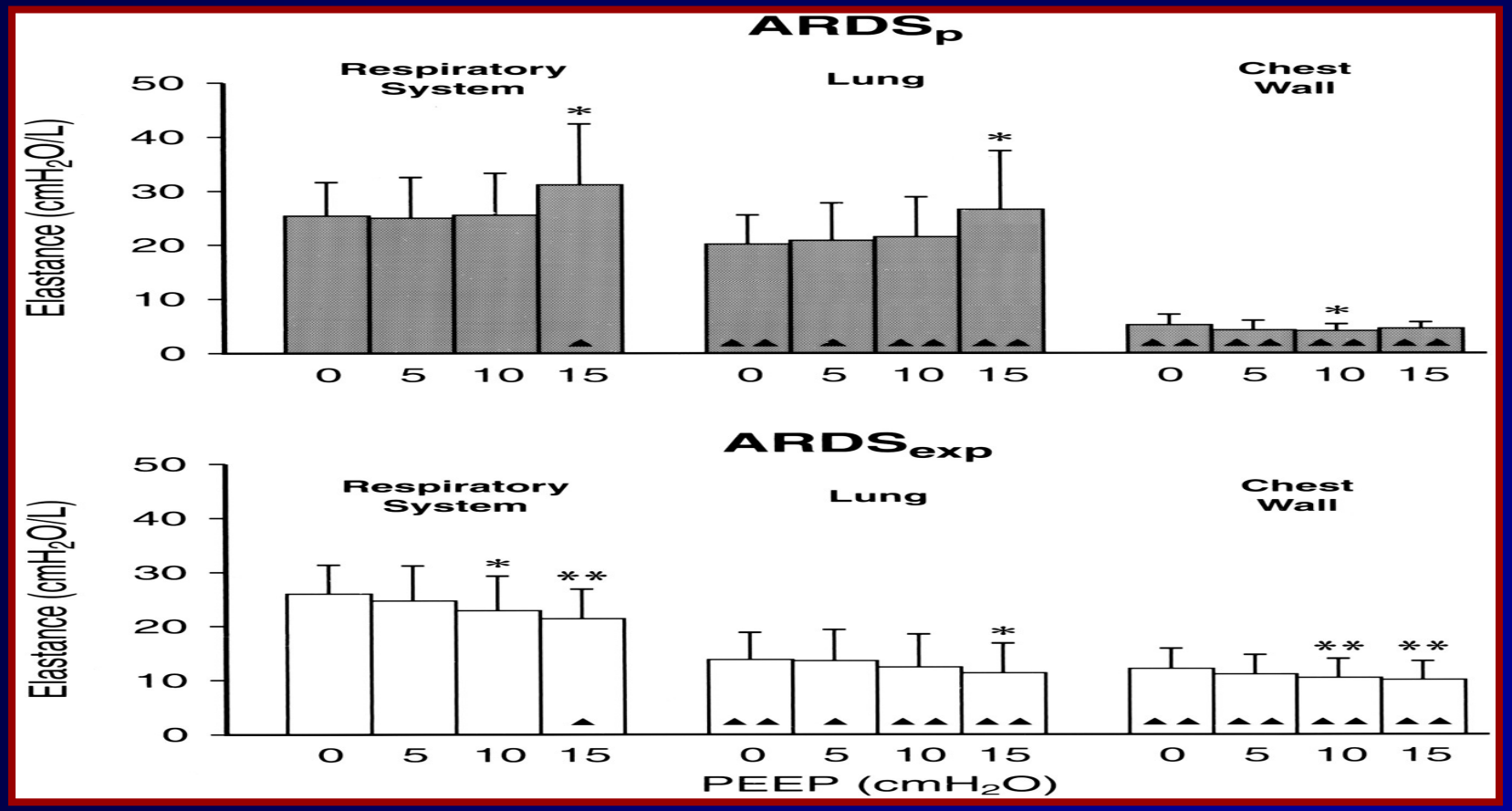


0 - (-5) = 5
Normal Vt



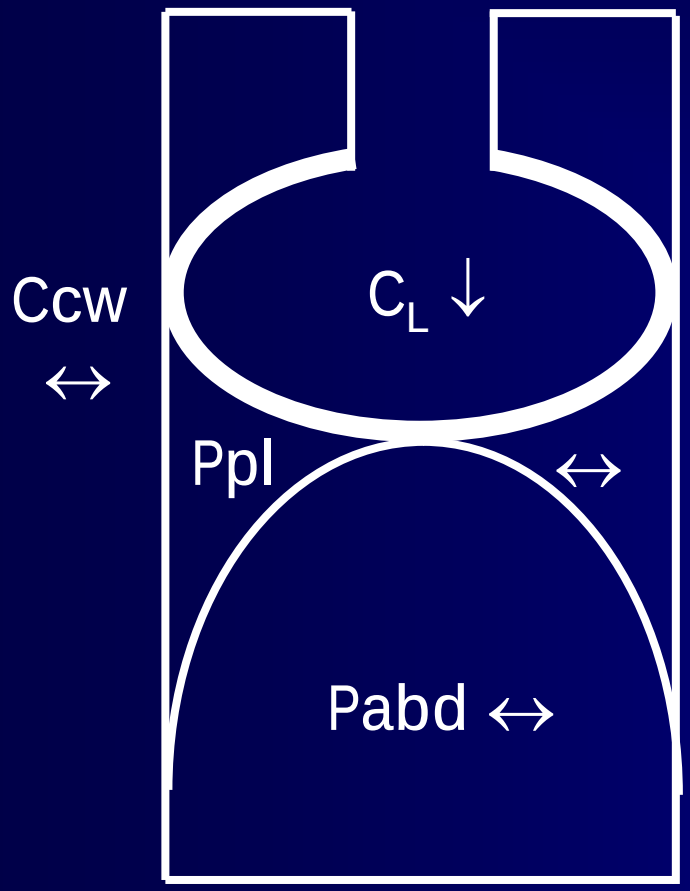
0 - (-35) = 35
Spontaneous TLC

Pleural Pressure Measurement
Pulmonary vs. Non-pulmonary ARDS



Gattinoni AJRCCM 1998;158:3-11

Pleural Pressure Measurement
Pulmonary ARDS

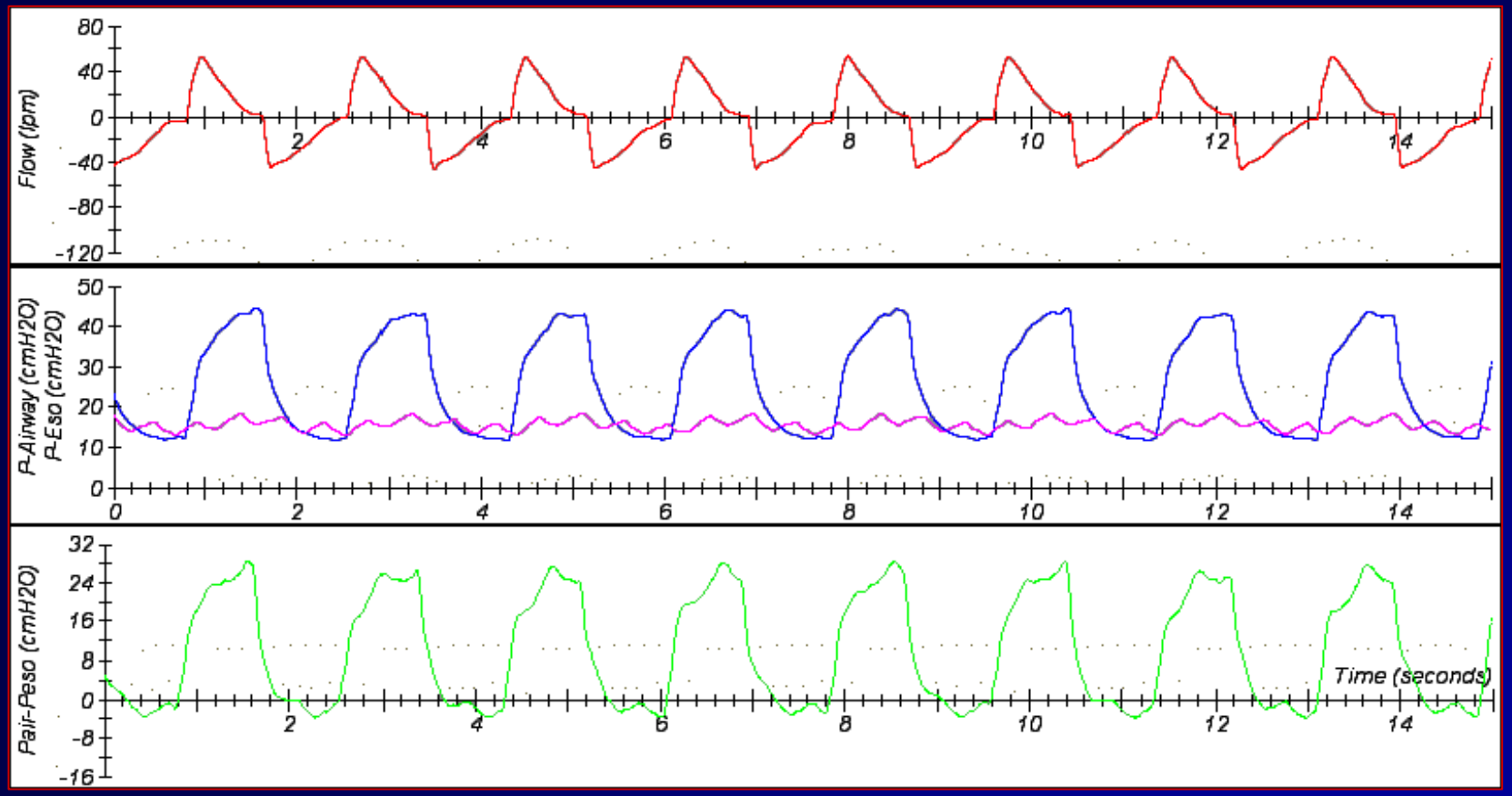


Stiff Lungs/Normal Chest Wall

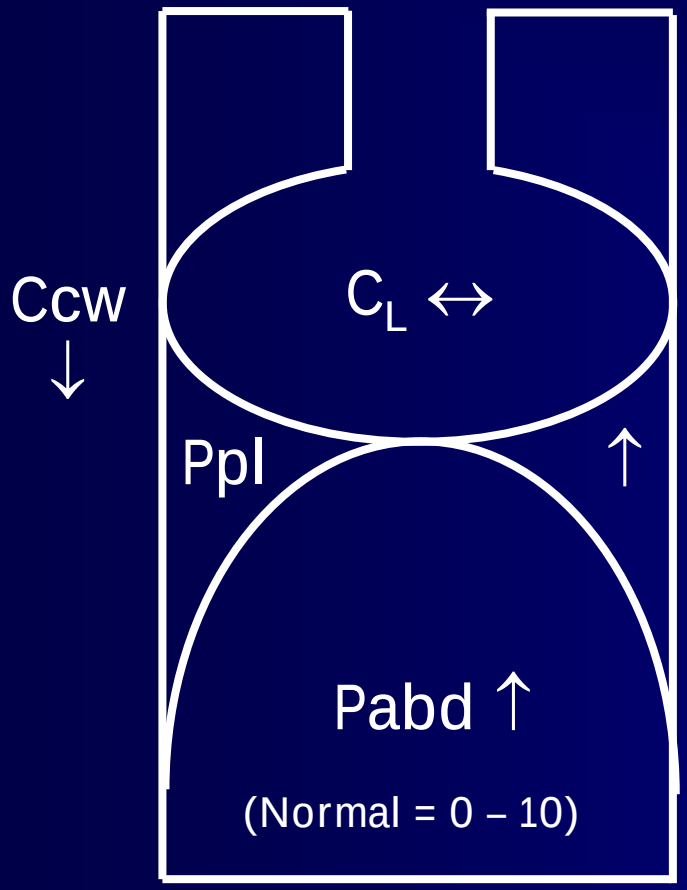
- Edema
  - interstitial
  - airspace
- Surfactant loss
- Fibrosis
- Consolidation
  - pneumonia
  - atelectasis

Pleural Pressure Measurement

Stiff Lungs, Compliant Chest Wall



Pleural Pressure Measurement
Non-Pulmonary ARDS



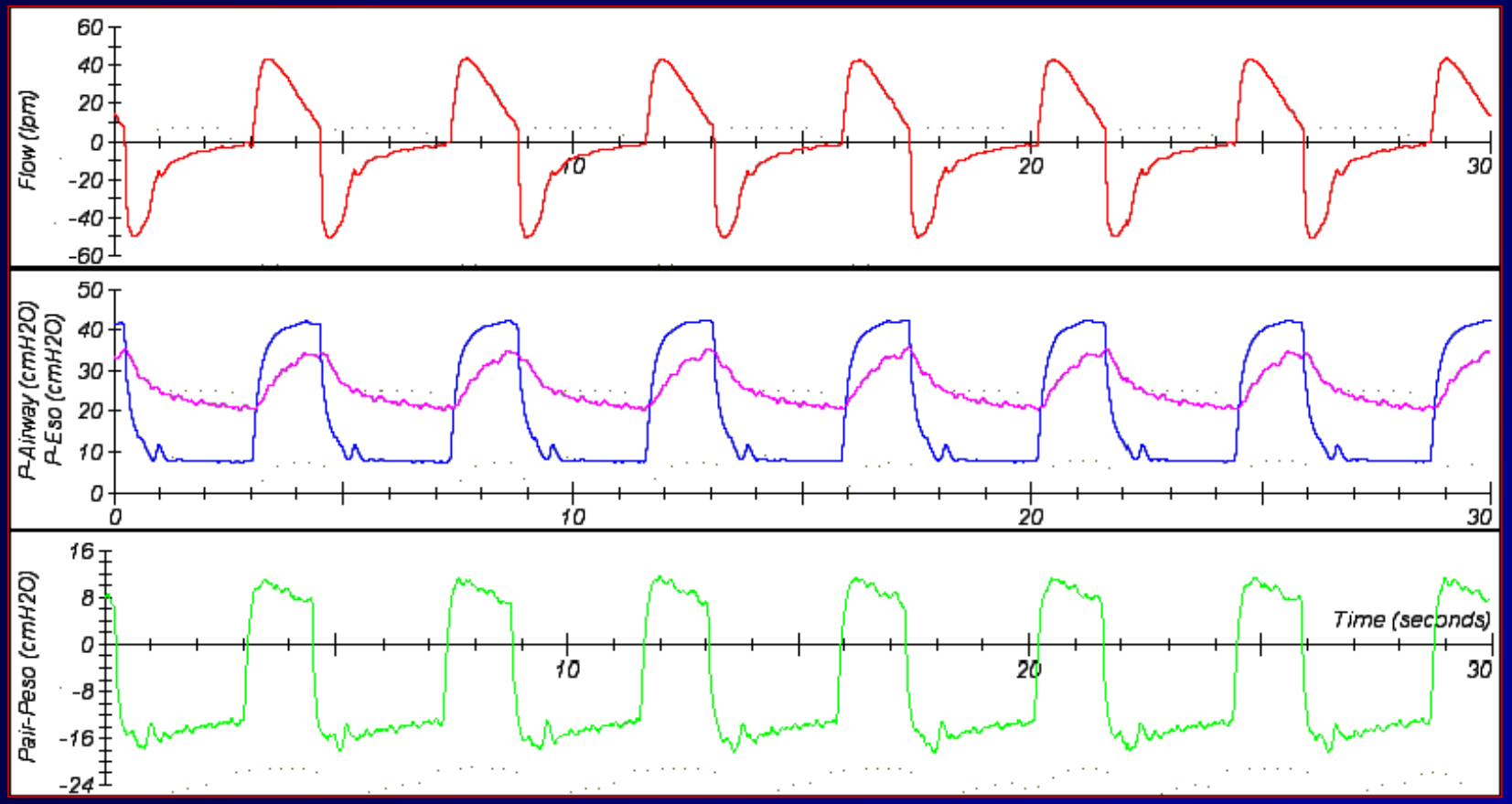
Stiff Chest Wall/Normal Lungs

- IAH
- Cardiomegaly
- Hemo/pneumo, etc.

- Chest wall deformity
- Flail

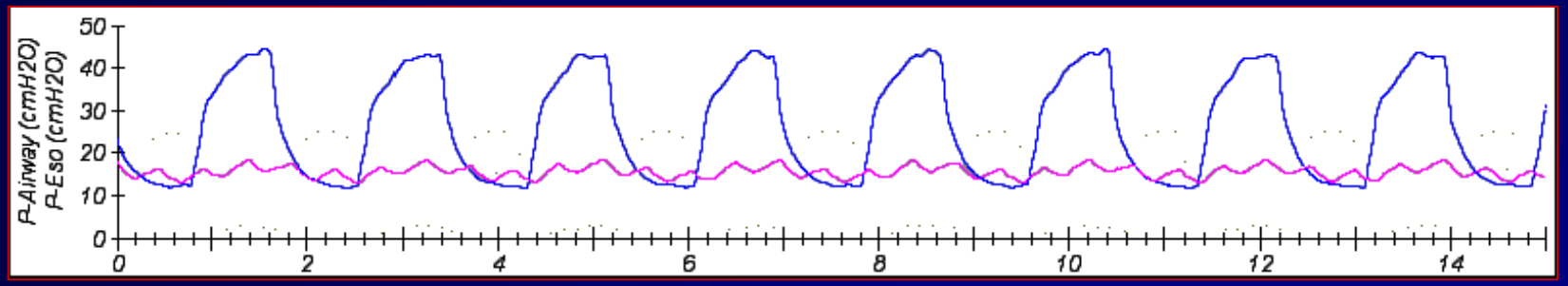
Pleural Pressure Measurement

Stiff Chest Wall, Compliant Lungs

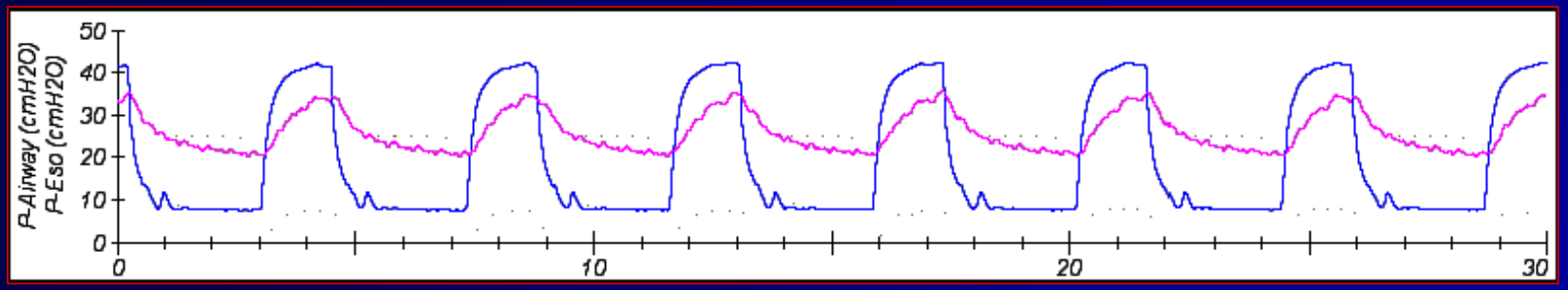


Pleural Pressure Measurement
Pulmonary vs Non-pulmonary ARDS

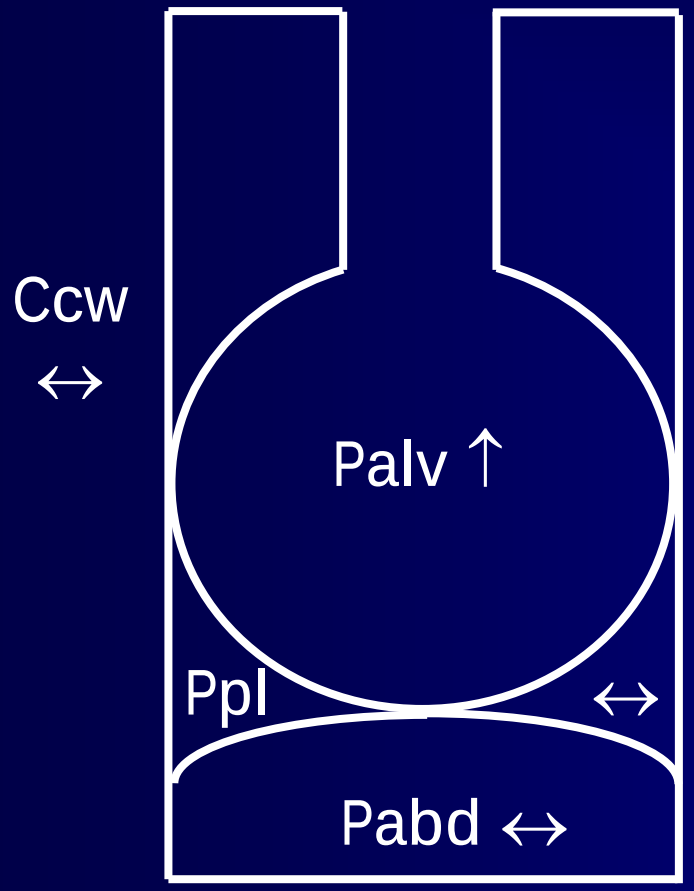
Pulmonary ARDS – Stiff Lungs/Normal Chest Wall



Non-Pulmonary ARDS – Normal Lungs/Stiff Chest Wall



Pleural Pressure Measurement
Mechanical Errors in Ventilation



Over-inflated Lungs

- Air trapping
  - asthma, COPD, etc.
- Vt too high
- $PEEP_{app}$ too high

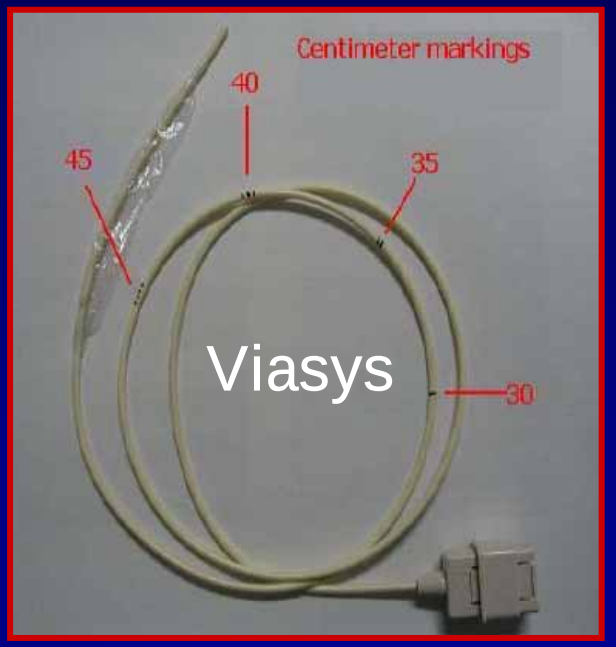
Pleural Pressure Measurement
Pulmonary Mechanic Monitors

Ventrak

Bicore

Avea Ventilator

Pleural Pressure Measurement
Esophageal Balloons



- Low- pressure balloon
- 9 to 10 cm long.
- Optimal fill vol.
  0.5 – 1.0 ml of air.

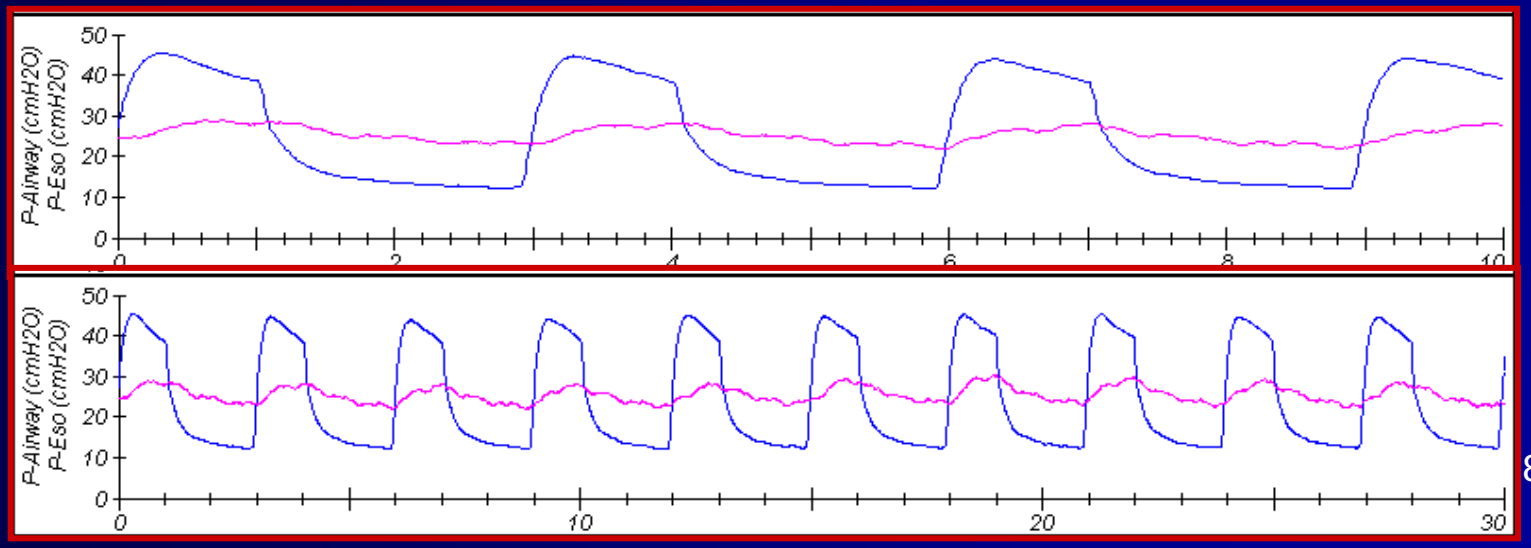
Contraindications
- recent gastric surgery
- esophageal varacies
- other esophageal injuries

Pleural Pressure Measurement
Balloon Insertion

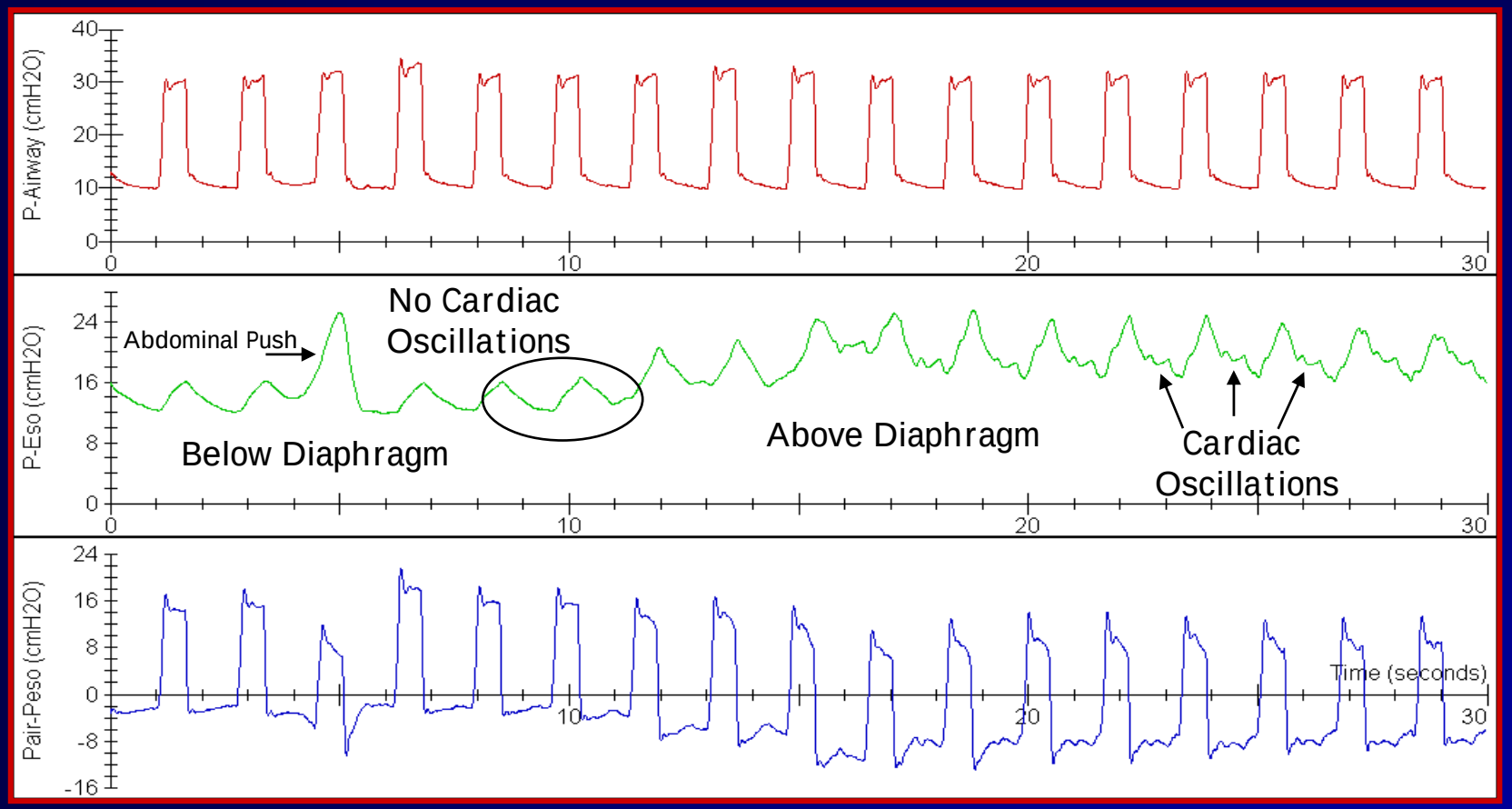
- Insert to 40 - 45 cm for Pes. (oral or nasal)
  - 60 cm for Pga.
- Pass next to or under ETT or OG tube
- Advance gently in short advances, 1 - 2 cm at a time.
    - avoids coiling in the upper airway.
- Don't advance during coughing, gagging or esophageal spasms.
- Fingers to clear soft tissue
    - insert bite block
- Assistant applies jaw thrust
- Use oral airway or "split" ETT

Pleural Pressure Measurement
Determining Correct Balloon Position

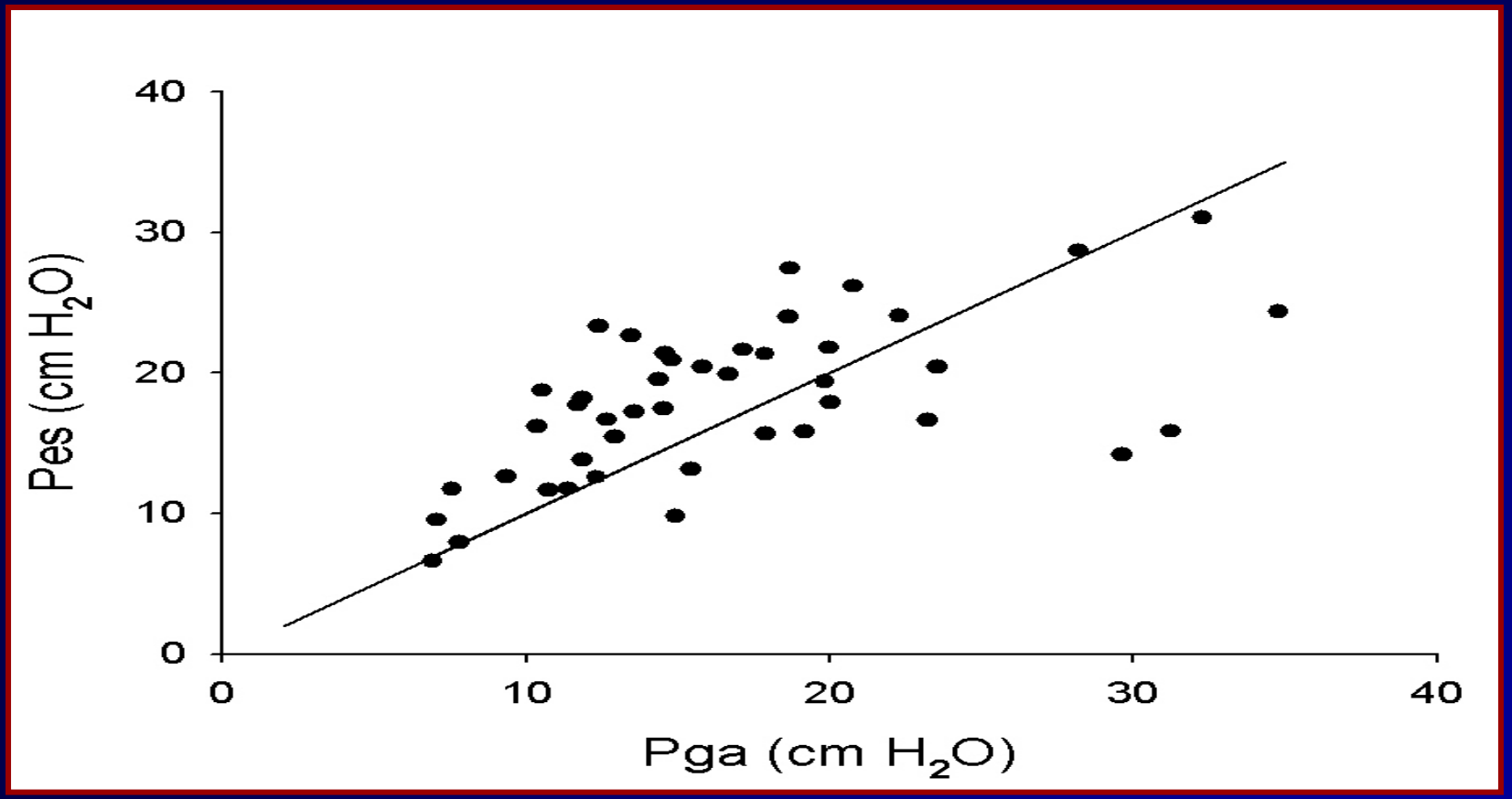
- Correct depth ≈ 40 cm H_2O for most patients.
- Note direction of Pes deflection.
- Verify cardiac oscillations in esophageal pressure.
- Pes is similar to Pga.
- Measurements must match the clinical presentation.



Pleural Pressure Measurement
Balloon Moved from Stomach to Chest

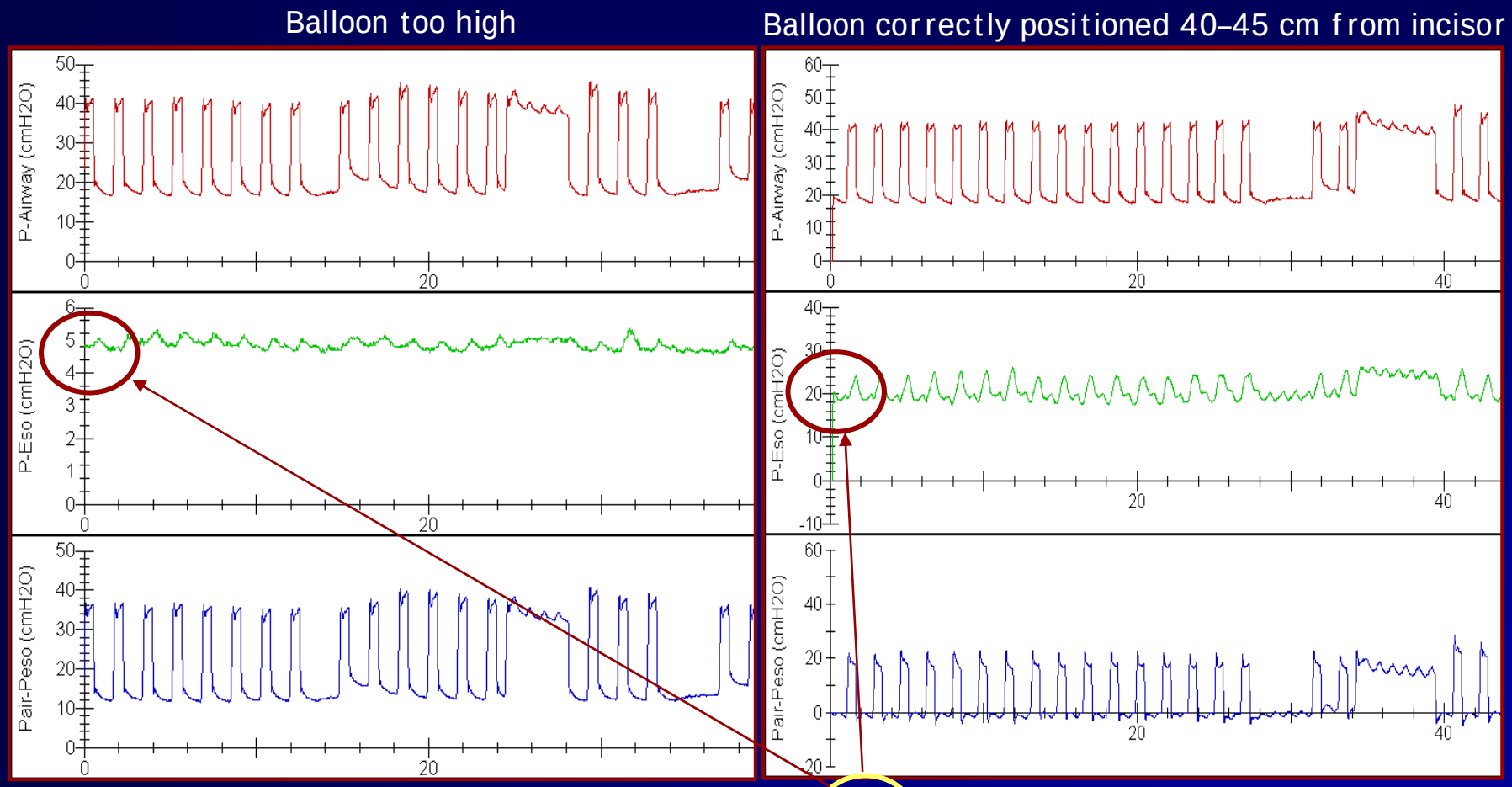


Pleural Pressure Measurement
Relationship between Pes and Pga

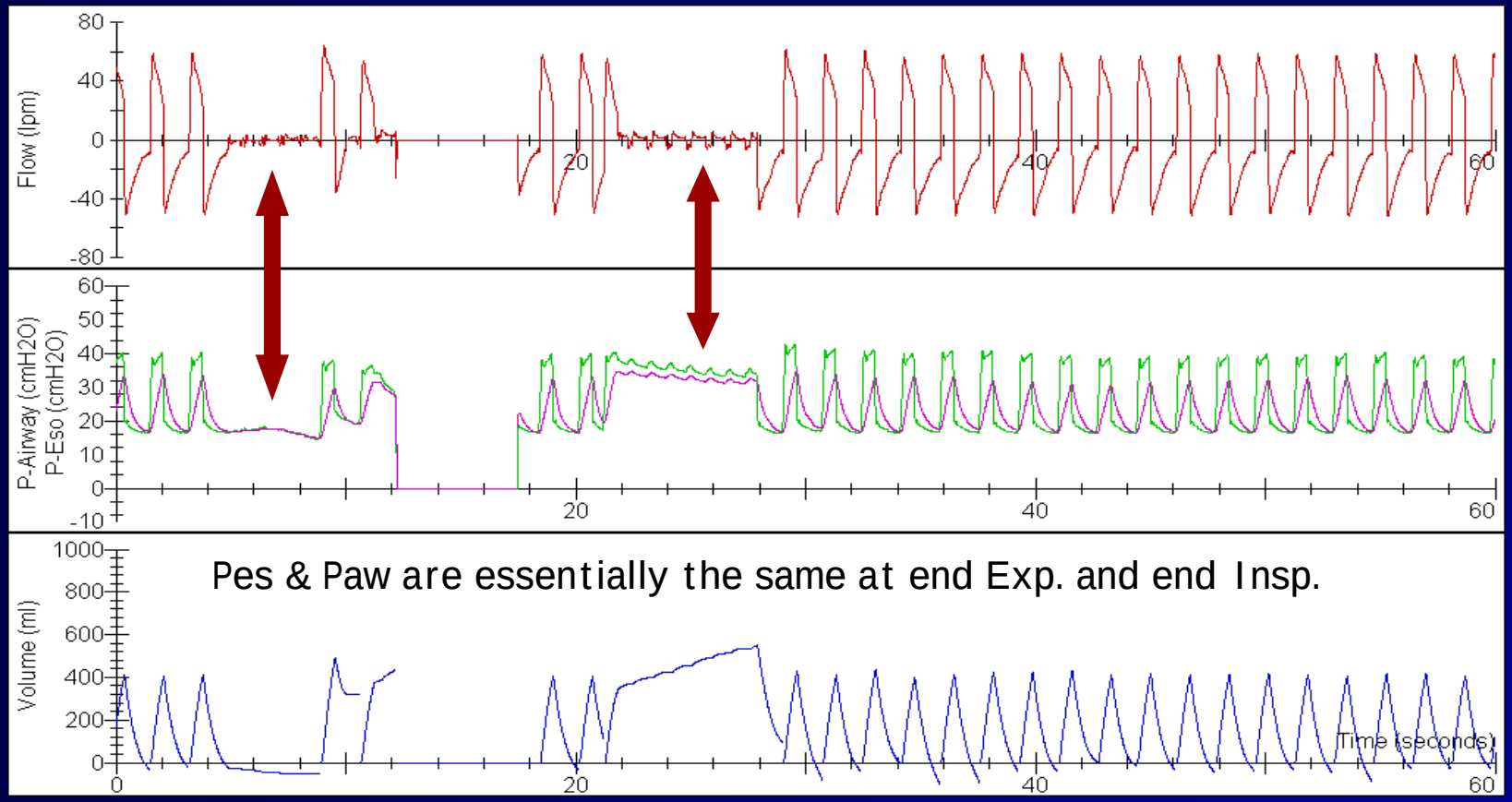


Talmor, CCM 2006, 34:1389-94

Pleural Pressure Measurement
Balloon at Thoracic Outlet

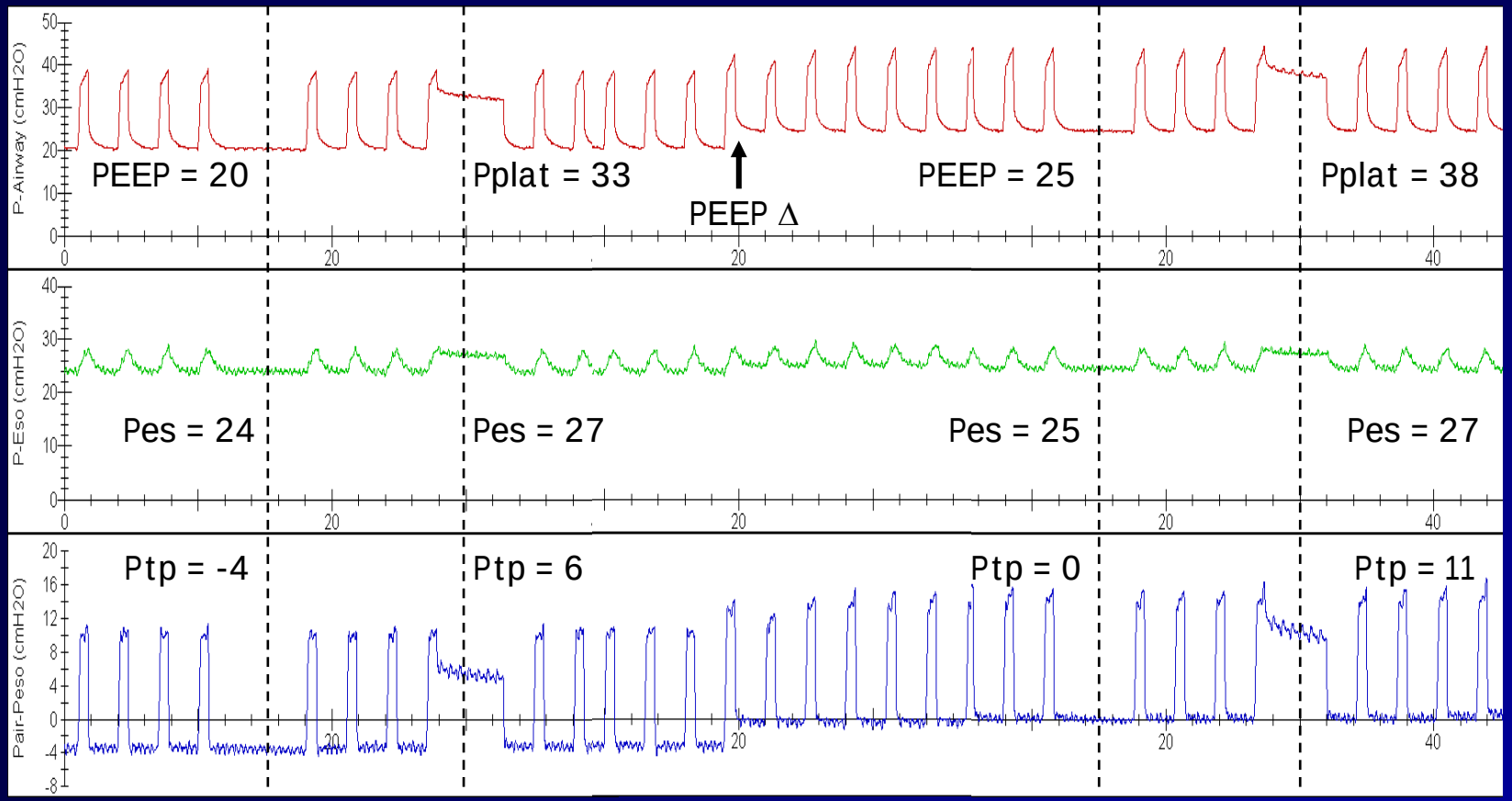


Pleural Pressure Measurement
Balloon in Airway



Pleural Pressure Measurement

Effect of PEEP Change



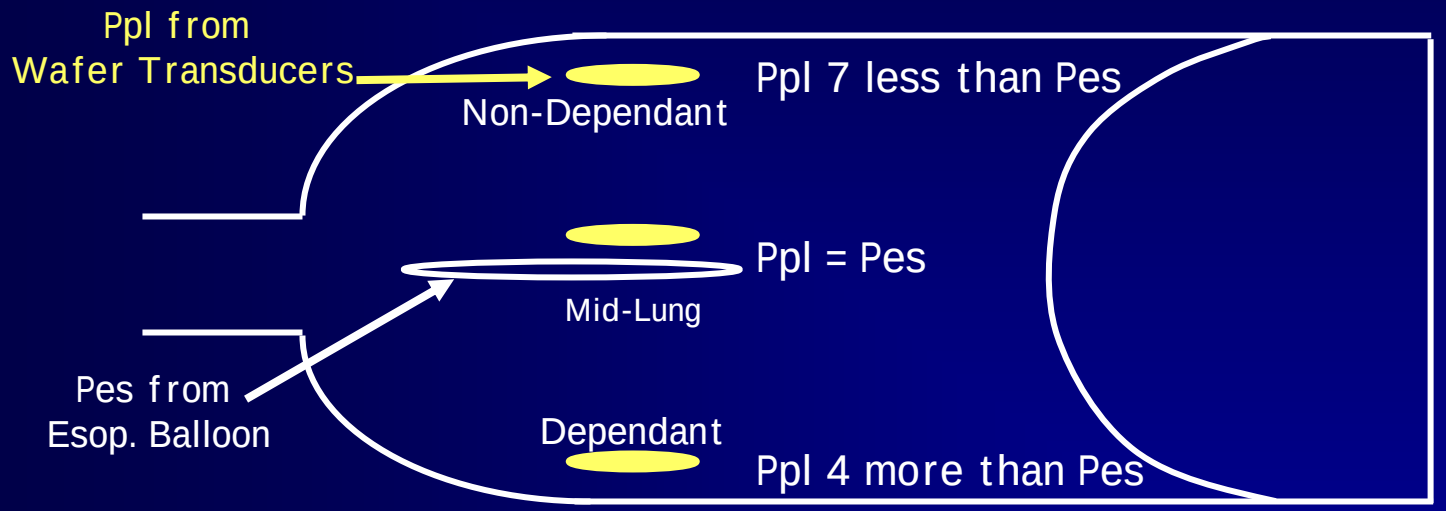
Pleural Pressure Measurement
Things that complicate measurement

- Gravity
- Position
- Active Exhalation
- Dis-synchrony
- Mechanical errors
- ? Pleural fluid
- ? Enlarged heart
- ? NG/OG tubes
- ? Chest tubes / suction

Pes measurements must match the patient's clinical presentation.

Pleural Pressure Measurement

Gravitational Effect on Regional Pleural Pressure



Pressure transducing wafers implanted in dog lungs revealed differences in pleural pressure due to the gravitational effect of the dependant vs. non-dependant regions of the lung.

Pelosi Am J Respir Crit Care Med 2001; 164:122-130

Pleural Pressure Measurement

Gravitational Effect on Regional Pleural Pressure

Pressure transducing wafers implanted in dog lungs revealed differences in pleural pressure due to the gravitational effect of the dependant vs. non-dependant regions of the lung.

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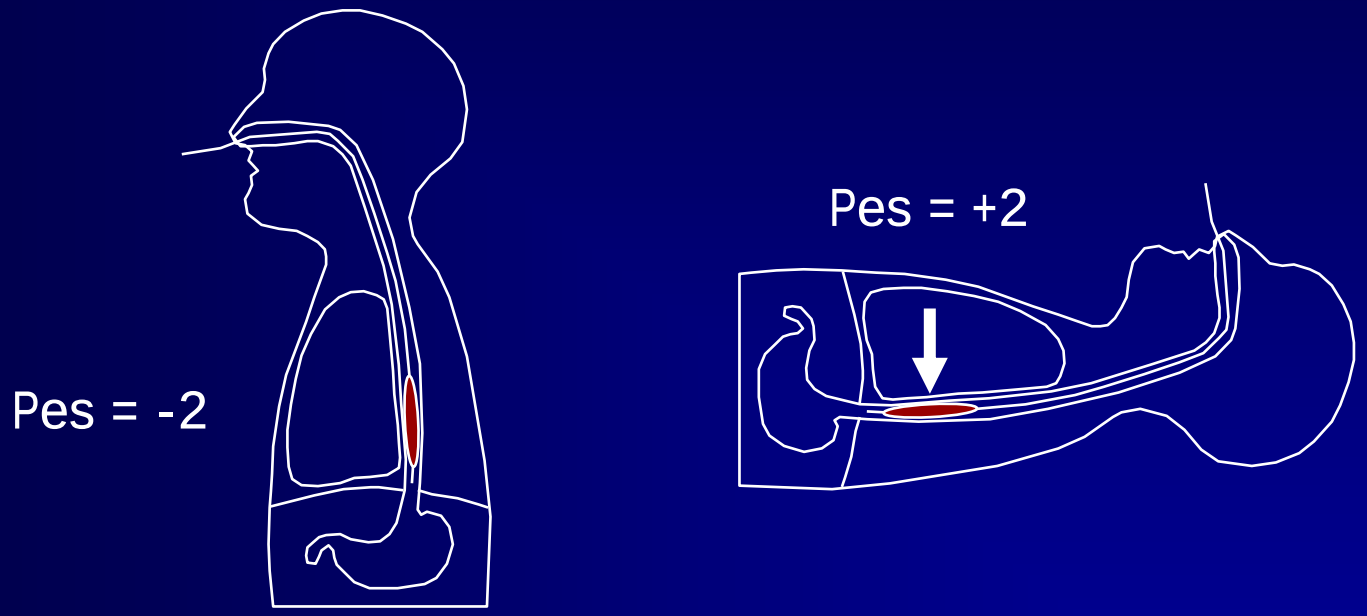
Pleural Pressure Measurement
Positional Artifact



Supine position causes approximately 3 – 4 cm H_2O increase in the transduced Pes due to heart & lung compression of the balloon.

Washko J Appl Physio 2006; 100:753-8

Pleural Pressure Measurement

EPVent Subjects

nejm 359;20 nov 13, 2008

	EP protocol N=30	Conventional N=31	p-value
Male gender, (%)	19 (63.3)	17 (54.8)	0.44
Age, years	54.5±16.1	51.2±23.0	0.52
Caucasian, (%)	26 (86.7)	27 (87.1)	0.96
Ideal body weight, kg	67.1±8.9	63.2±11.1	0.14
APACHE II on admission, points	26.3±6.4	26.8±6.5	0.76
Primary physiological injury (%)			
Pulmonary	7 (23.3)	5 (16.1)	0.54
Abdominal	13 (43.3)	11 (35.5)	
Trauma	6 (20.0)	9 (29.0)	
Sepsis	3 (10.0)	2 (6.5)	
Other	1 (3.3)	4 (12.9)	

Pleural Pressure Measurement

Physiologic Status at Baseline nejm 359;20 nov 13, 2008

	Baseline		
	EP protocol	Conventional	P-value
	N=30	N=31	
PaO_2 / F_IO_2 ratio	147 ± 56	145 ± 57	0.89
Respiratory Compliance, ml/cmH_2O	36 ± 12	36 ± 10	0.94
Dead space to tidal volume ratio, %	67.± 11.	67 ± 9	0.95
PaO_2, mmHg	91 ± 25	107 ± 44	0.09
F_IO_2, %	66 ± 17	77 ± 18	0.02
PEEP, cmH_2O	13 ± 5	13 ± 3	0.73
Tidal volume, cc^3	484 ± 98	491 ± 105	0.80
Tidal volume/ ideal body weight, cc/kg	7.3 ± 1.3	7.9 ± 1.4	0.12

Pleural Pressure Measurement
Study Protocol (NEJM 2008,359(20);2095:104)

ARDSnet Protocol: Mode – CMV; Pplat ≤ 30 cm H_2O

FiO_2	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.7	0.8	0.9	0.9	0.9	1.0
PEEP	5	5	8	8	10	10	10	12	14	14	14	16	18	20-24

Esophageal Balloon Directed Protocol: Mode – CMV; Ptp_{insp} ≤ 25 cm H_2O

FiO_2	0.4 – 0.5	0.5 – 0.6	0.6 – 0.7	0.7 - .08	0.8 – 0.9	0.9 – 1.0
Ptp_{exp}	0	+2	+4	+6	+8	+10

$Ptp_{exp} = PEEP_{tot} - P_{esoph}$ $Ptp_{insp} = Pplat - P_{esoph}$

Pleural Pressure Measurement
Study Protocol (Revised for Multi-center Trial *)

Esophageal Balloon Directed Protocol: Mode – CMV; $Ptp_{insp} \leq 25$ cm H_2O

Original FiO_2 to PEEP Management Grid (NEJM 2008,359(20);2095:104)

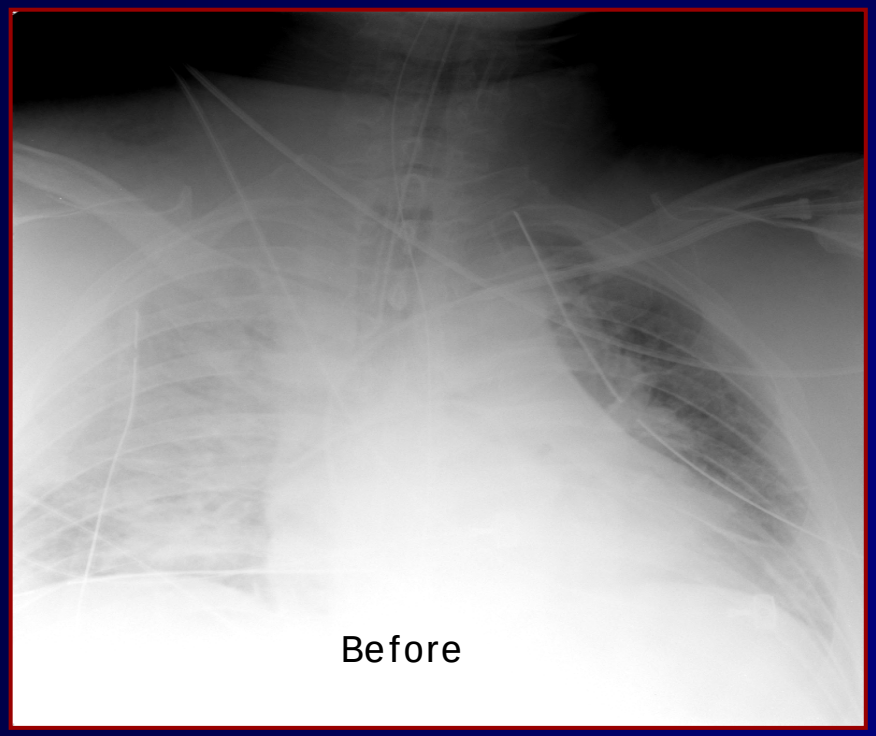
FiO_2	0.4 – 0.5	0.5 – 0.6	0.6 – 0.7	0.7 - .08	0.8 – 0.9	0.9 – 1.0
Ptp_{exp}	0	+2	+4	+6	+8	+10

Revised FiO2 to PEEP Management Grid for Proposed Multi-center trial

FiO_2	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Ptp_{exp}	0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7

$Ptp_{exp} = PEEP_{tot} - P_{esoph}$ $Ptp_{insp} = Pplat - P_{esoph}$

Pleural Pressure Measurement
EP Vent Study Patient

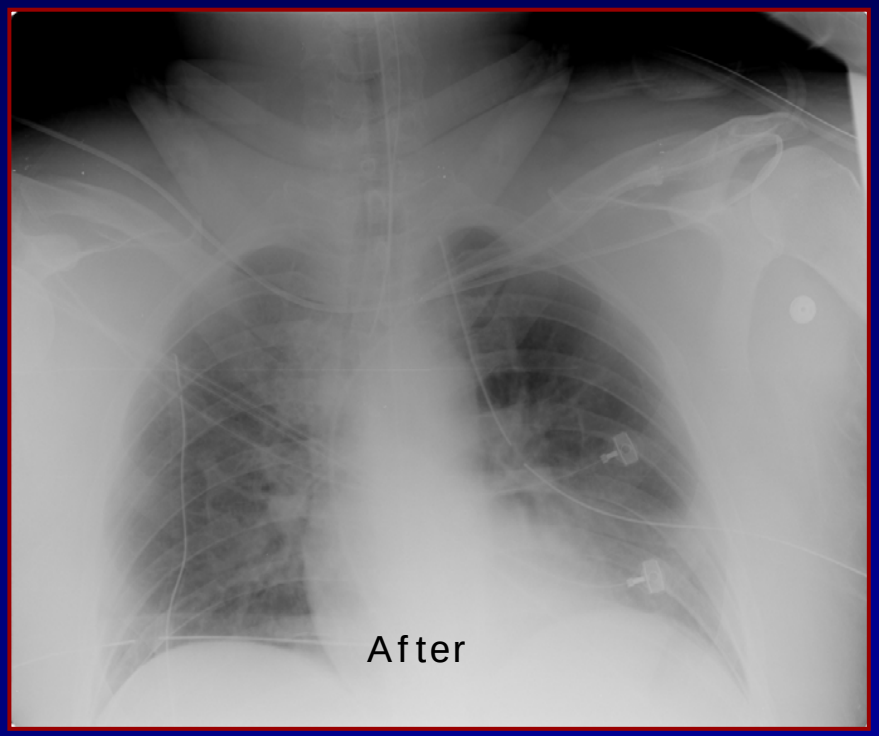


P_{aw} = 13 to **40**

Pplat = 40

P_{es} = 20 to 33

P_{tp} = -7 to 7



P_{aw} = 26 to 46

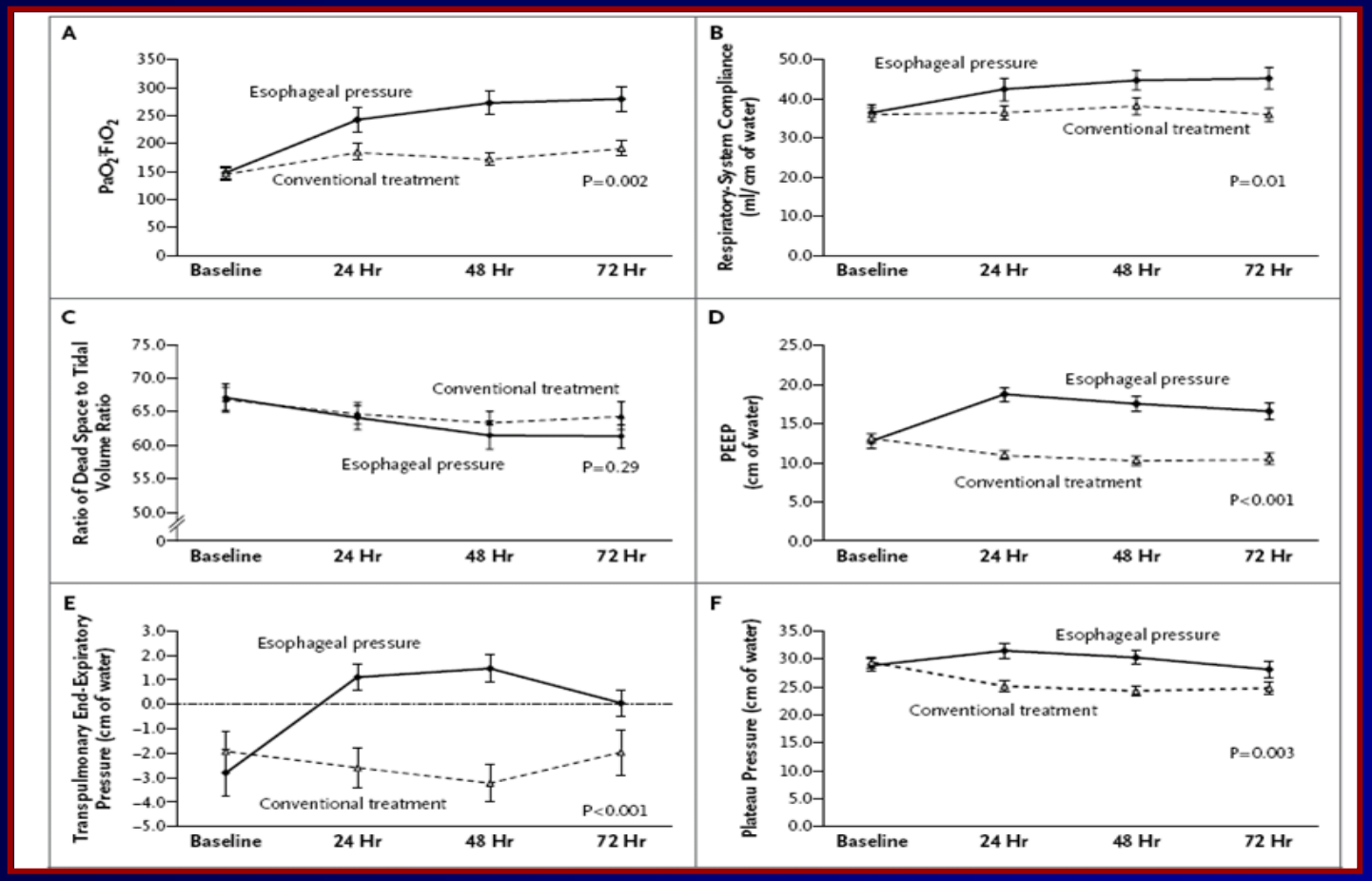
Pplat = 46

P_{es} = 22 to 33

P_{tp} = 4 to 13

Pleural Pressure Measurement

MV Guided by Pes Pr in ALI nejm 359;20 nov 13, 2008



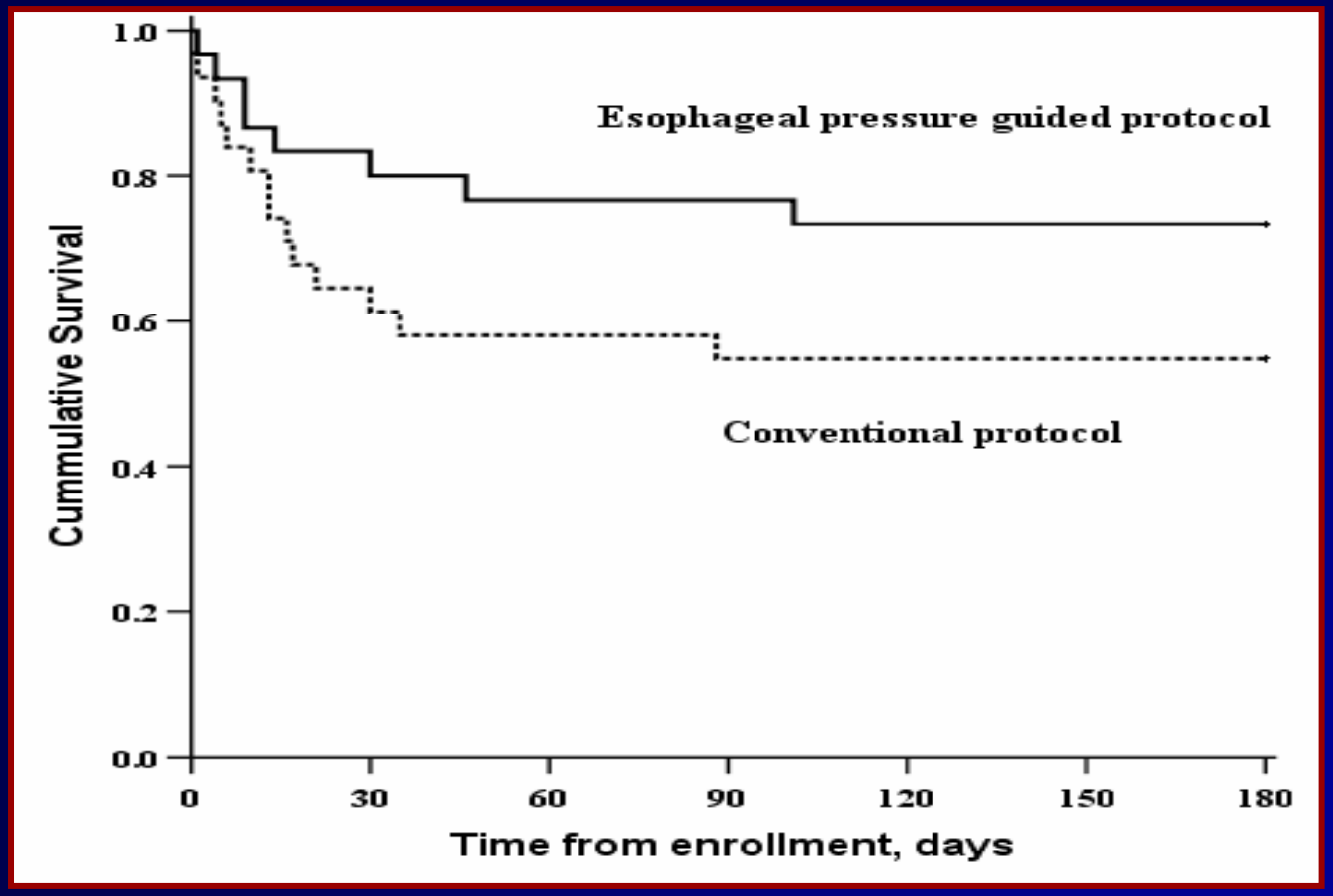
Pleural Pressure Measurement

MV Guided by Pes Pr in ALI NEJM 2008, 359(20);2095-104

	EP protocol N=30	Conventional N=31	p-value
28-day mortality, (%)	5 (16.7)	12 (38.7)	0.055
6-month mortality (%)	8 (26.7)	14 (45.3)	0.13
ICU length of stay, days, median (IQR)	15.5 (10.8-28.5)	13.0 (7.0-22.0)	0.16
ICU free days at 28 days, median (IQR)*	5.0 (0.0-14.0)	4.0 (0.0-16.0)	0.96
Ventilator free days at 28 days, median (IQR)*	11.5 (0-20.3)	7 (0-17)	0.50
Days on ventilator for survivors, days, median (IQR)*	12.0 (7.0-27.5)	16 (7.0-20.0)	0.71

Pleural Pressure Measurement

MV Guided by Pes Pr in ALI NEJM 2008, 359(20);2095-104



6 Month Survival

Pleural Pressure Measurement
Summary

- Pes closely approximates Ppl.
- Ppl can vary in the pleural space.
- Ptp can help to limit re-inflation lung injury.
- Ptp can help avoid over-inflation.

- Clinical targets:
  - End Expiratory Ptp $\cong$ 0 cm H_2O
  - End Inspiratory Ptp < 25 cm H_2O
    - The lower the End Insp Ptp, the lower the lung stress!!

The End (Whew!!!)

Thank You

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