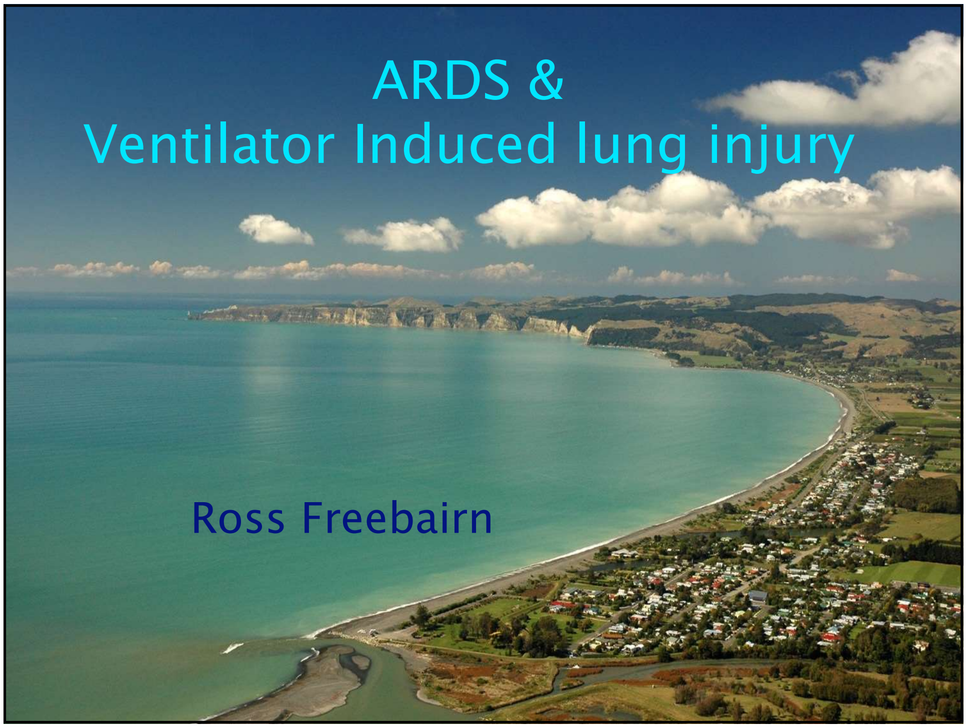
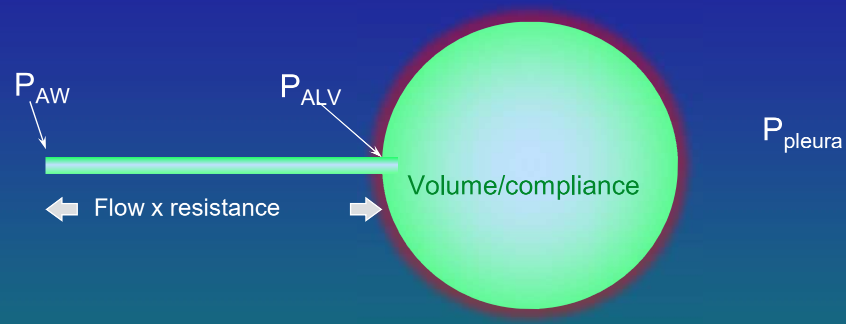

ARDS &
Ventilator Induced lung injury
Ross Freebairn

1


BILEVEL VENTILATION
Proportional Assist
CONFUSION
IPPV
IPPRV
PSV
PAP
CMV
BIPAP
APRV
MMV
VC
JET VENTILATION
SIMV(vol)/ PS
HFO

2

Alveolar and Trans-alveolar Pressure



$$P_{aw} = Flow \times Resistance + \frac{Volume}{Compliance} + PEEP$$

$$P_{alv} = \frac{Volume}{Compliance} + PEEP$$

$$P_{trans\ alv} = P_{alv} - P_{pleural}$$

3

120/4/grid@150

AP ERECT

PORTABLE

ARDS is sinister

Occurs In

- 10% of ICU patients
- 23% of patients on mechanical ventilation

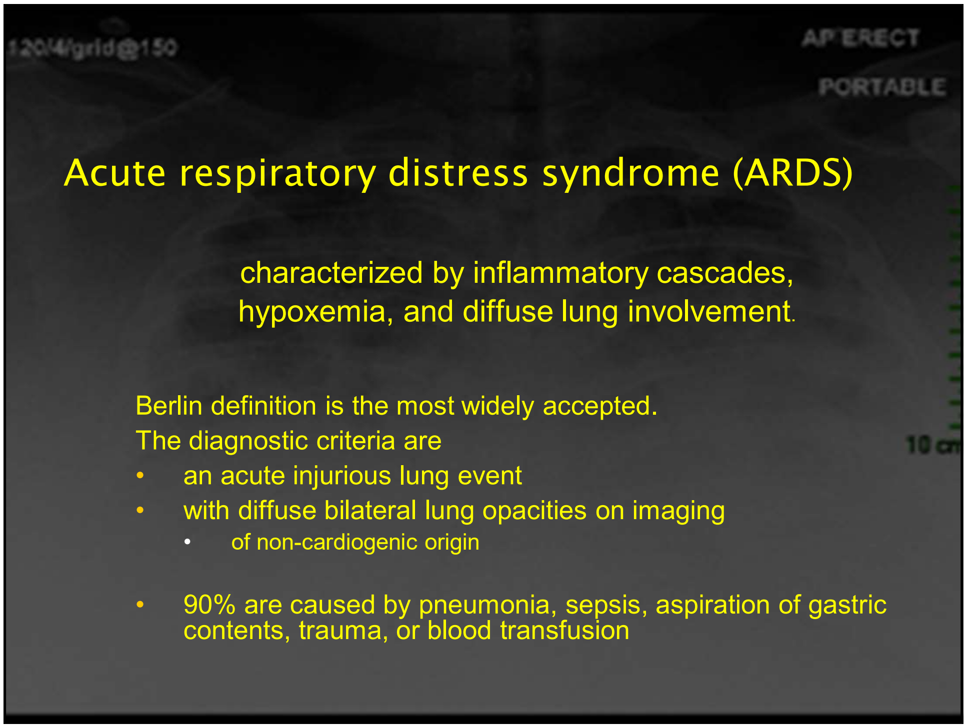
Mortality

Age 15 -19 years =24%,

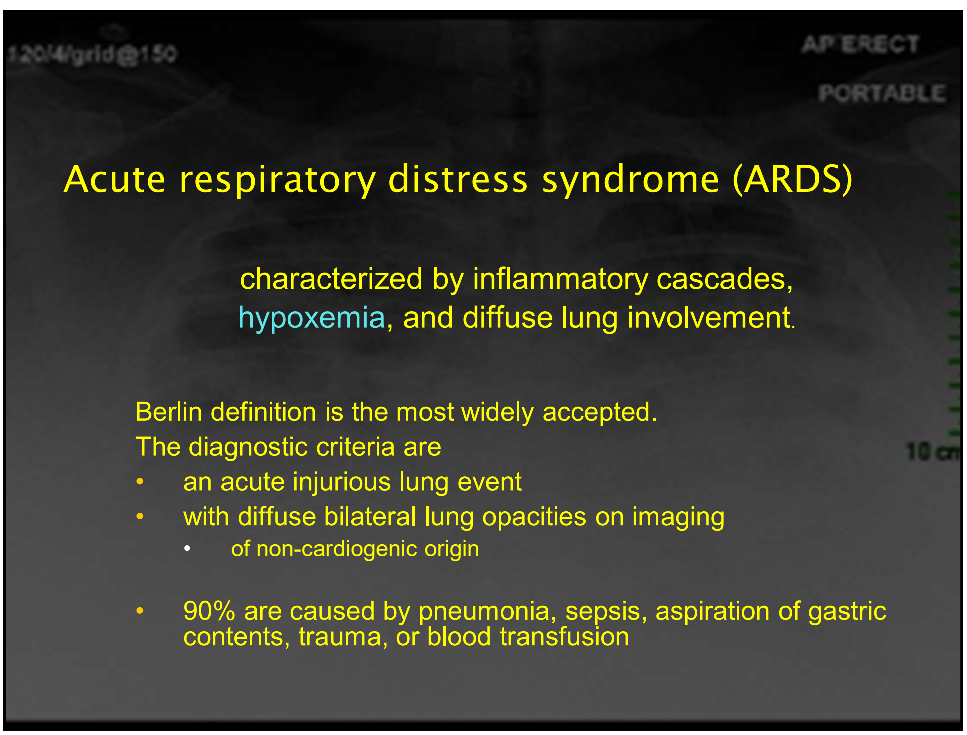
Age > 50 = 60%

Rubenfeld, G.D.; Caldwell, E.; Peabody, E.; Weaver, J.; Martin, D.P.; Neff, M.; Stern, E.J.; Hudson, L.D. Incidence and outcomes of acute lung injury. N. Engl. J. Med. 2005, 353, 1685-1693.

4


120/4/grid@150
AP ERECT
PORTABLE
Acute respiratory distress syndrome (ARDS)
characterized by inflammatory cascades, hypoxemia, and diffuse lung involvement.
Berlin definition is the most widely accepted.
The diagnostic criteria are
• an acute injurious lung event
• with diffuse bilateral lung opacities on imaging
• of non-cardiogenic origin
• 90% are caused by pneumonia, sepsis, aspiration of gastric contents, trauma, or blood transfusion
10 cm

5


120/4/grid@150
AP ERECT
PORTABLE
Acute respiratory distress syndrome (ARDS)
characterized by inflammatory cascades, hypoxemia, and diffuse lung involvement.
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• an acute injurious lung event
• with diffuse bilateral lung opacities on imaging
• of non-cardiogenic origin
• 90% are caused by pneumonia, sepsis, aspiration of gastric contents, trauma, or blood transfusion
10 cm

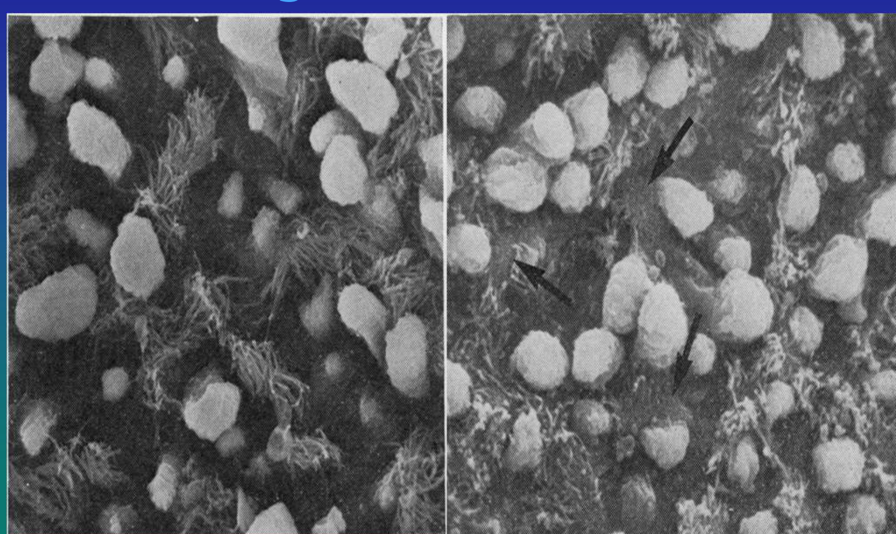
6

How do we increase oxygenation

- Oxygen in
  - □ □ F_IO_2
  - □ □ mean alveolar pressure
    - TV
    - Increased Inspiratory time PAUSE/I:E/
    - PEEP
  - PEEP
    - Re-open alveoli and □ shunt
  - RECRUITMENT
    - Re-open alveoli and □ shunt
  - Prone Positioning

7

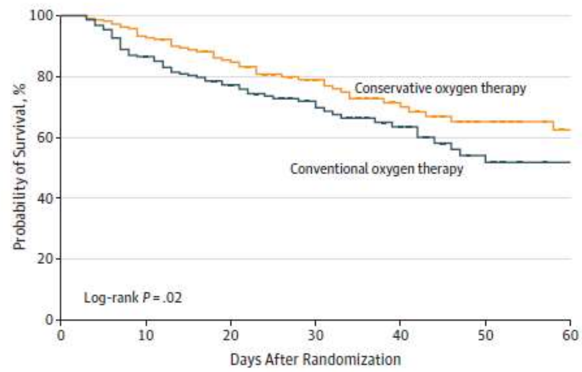
Changes to Tissues with 0_2



Obara H et al. Thorax, 1979, 34, 479-485 Alterations to the bronchial and bronchiolar surfaces of adult mice after exposure to high concentrations of oxygen

8

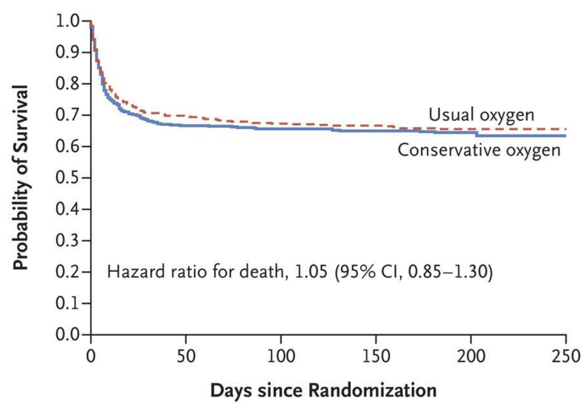
Figure 2. Probability of Survival From Study Inclusion (Day 0) Through Day 60 for Patients in the Conservative and Conventional Oxygen Strategy Groups



No. at risk							
Conservative oxygen therapy	216	201	188	181	173	170	169
Conventional oxygen therapy	218	189	172	163	158	152	152

JAMA. 2016;316(15):1583-1589. doi:10.1001/jama.2016.11993
Published online October 5, 2016.

Kaplan–Meier Estimates of Survival.



No. at Risk						
Usual oxygen	481	334	319	314	69	13
Conservative oxygen	484	319	313	310	73	11

The ICU-ROX Investigators and the Australian and New Zealand Intensive Care Society Clinical Trials Group. N Engl J Med 2020;382:989-998

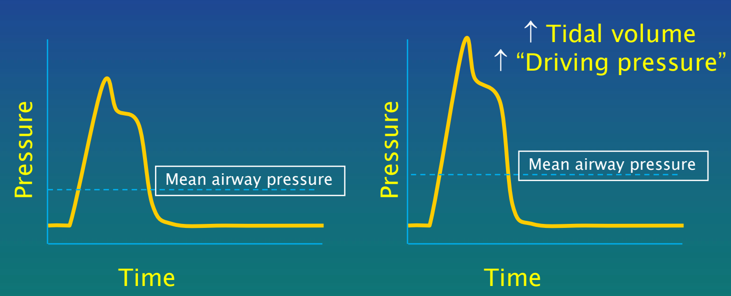
The NEW ENGLAND JOURNAL of MEDICINE

How do we increase oxygenation

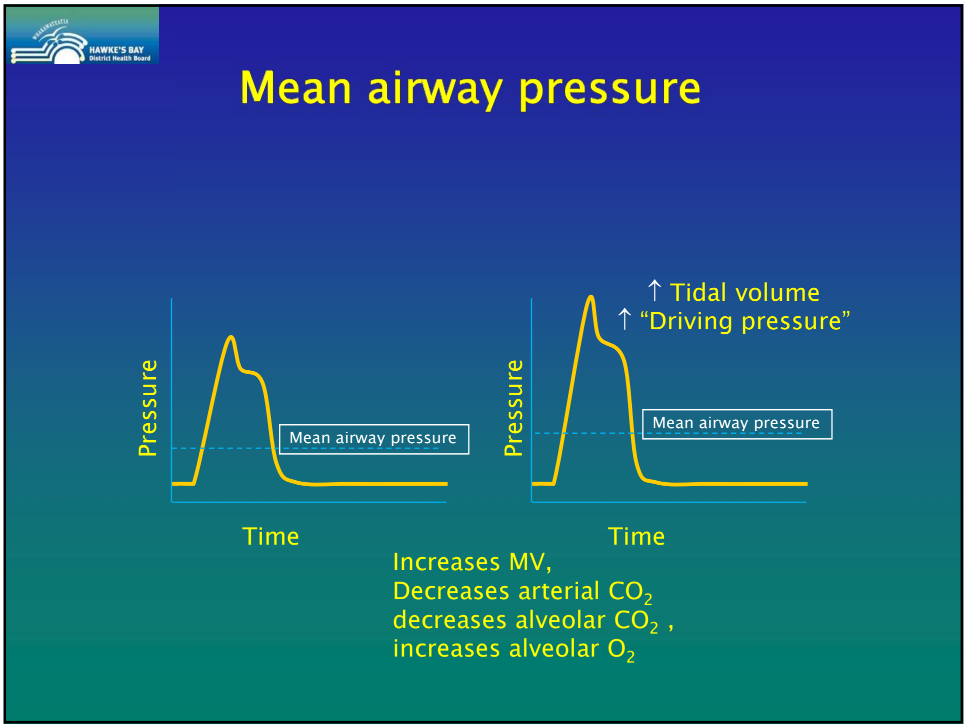
- Oxygen in
  - □ □ FIO2
  - □ □ mean alveolar pressure
    - TV
    - Increased Inspiratory time PAUSE/I:E/
    - PEEP
  - PEEP
    - Re-open alveoli and □ shunt
  - RECRUITMENT
    - Re-open alveoli and □ shunt
  - Prone Positioning

11

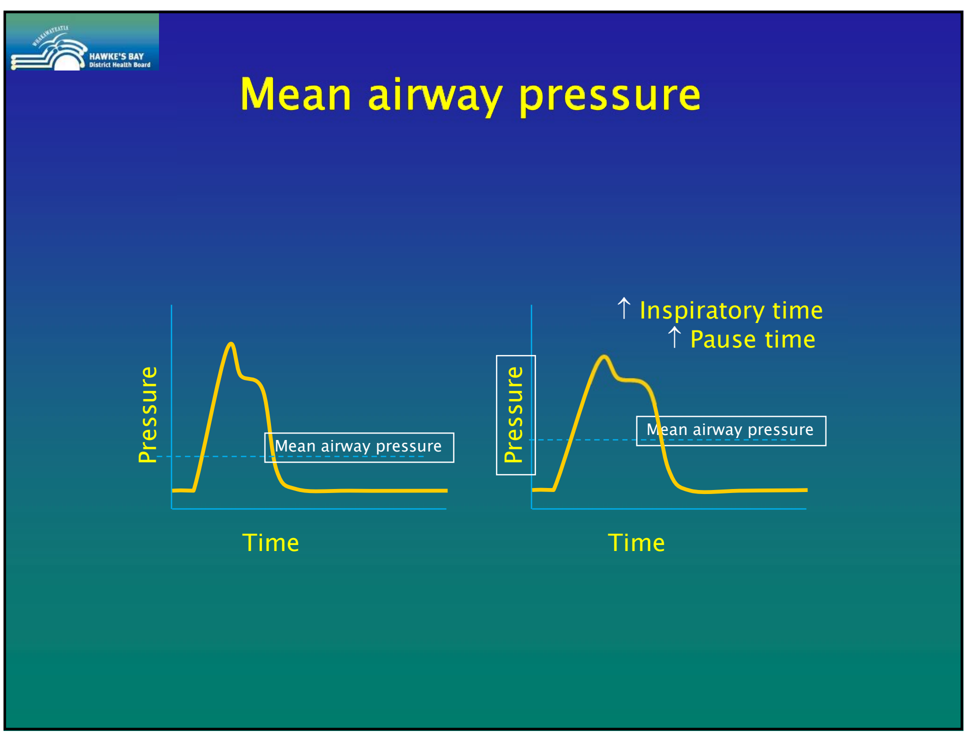
Mean airway pressure



12

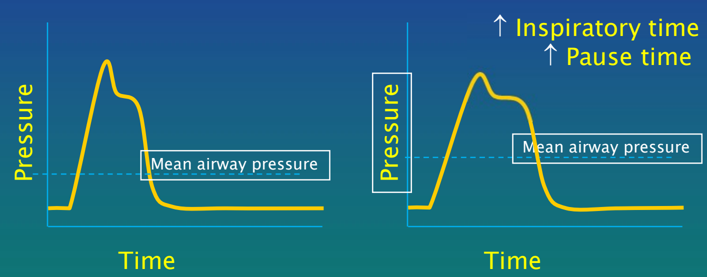

HAWKE'S BAY District Health Board
Mean airway pressure
↑ Tidal volume
↑ "Driving pressure"
Pressure
Mean airway pressure
Time
Pressure
Mean airway pressure
Time
Increases MV,
Decreases arterial CO_2
decreases alveolar CO_2 ,
increases alveolar O_2

13


HAWKE'S BAY District Health Board
Mean airway pressure
↑ Inspiratory time
↑ Pause time
Pressure
Mean airway pressure
Time
Pressure
Mean airway pressure
Time

14

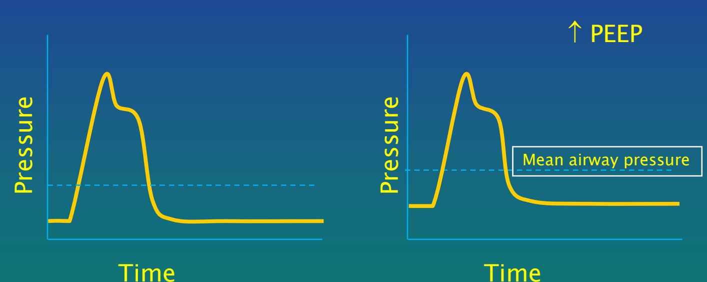
Mean airway pressure



Increases redistribution to alveolar sacs with long time constants those with higher resistance and higher compliance

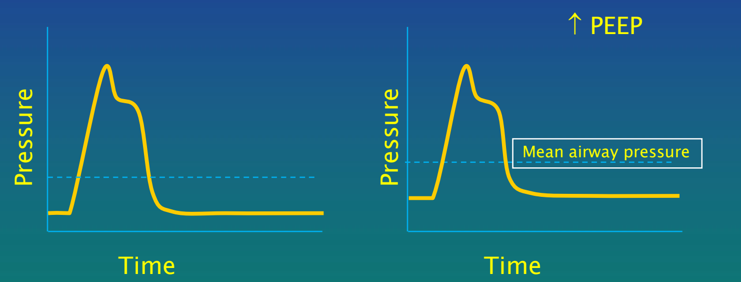
15

Mean airway pressure



16

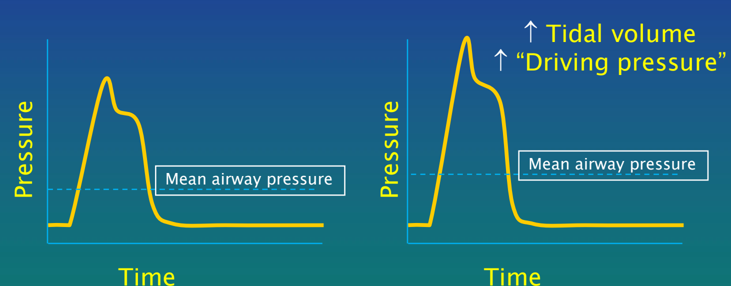
Mean airway pressure



Reopens and or prevents tidal collapse of alveoli.

17

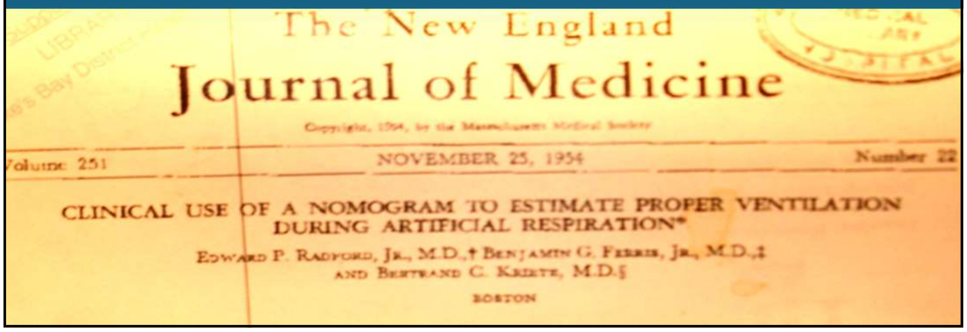
Mean airway pressure: TV?



18

Appropriate tidal ventilation?

- Tidal volume formula constructed for "proper ventilation":
  - Nomogram giving TV 6- 8 ml/kg
    - Radford, E.P., Jr., B.G. Ferris, Jr., and B.C. Kriete, *Clinical use of a nomogram to estimate proper ventilation during artificial respiration.* N Engl J Med, 1954. **251**(22): p. 877-84


The New England
Journal of Medicine
Volume 251 NOVEMBER 25, 1954 Number 22
CLINICAL USE OF A NOMOGRAM TO ESTIMATE PROPER VENTILATION DURING ARTIFICIAL RESPIRATION*
EDWARD P. RADFORD, JR., M.D.,† BENJAMIN G. FERRIS, JR., M.D.,‡ AND BERTRAND C. KRIETE, M.D.§
BOSTON

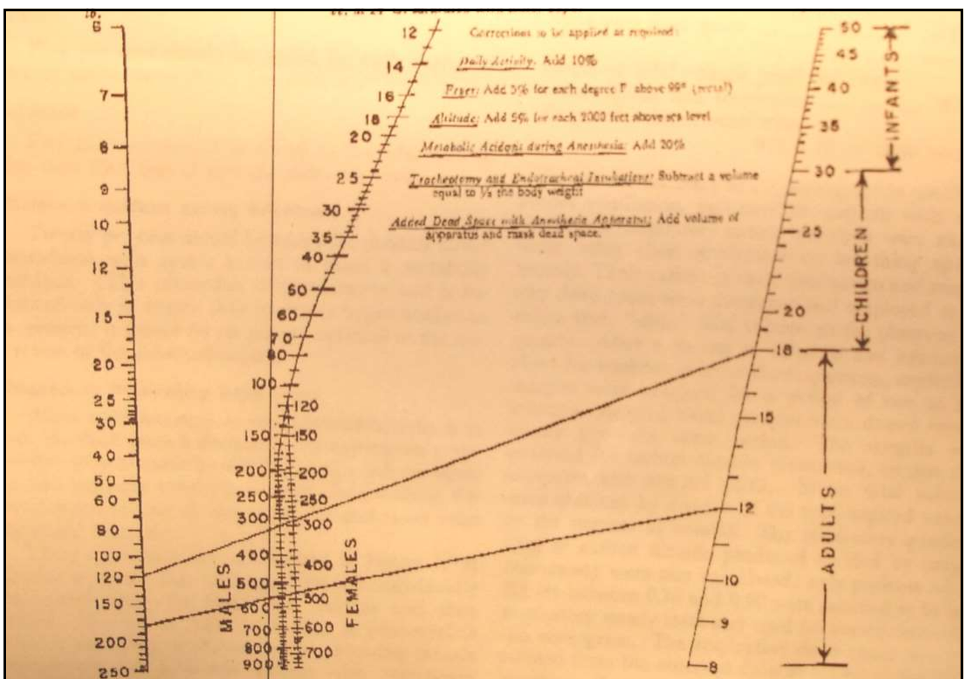
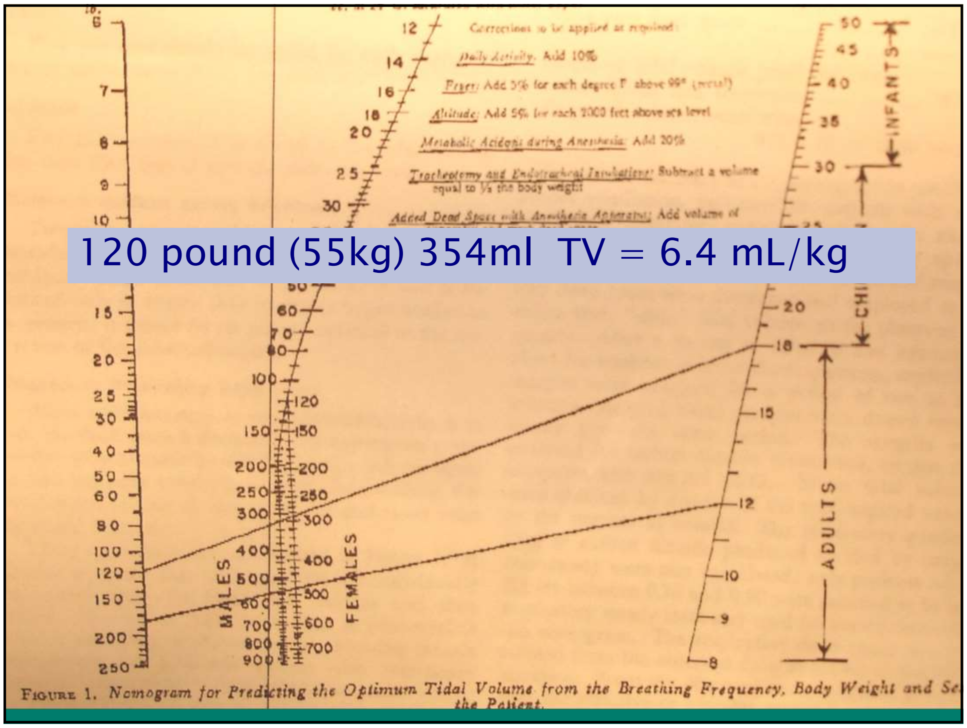


FIGURE 1. Nomogram for Predicting the Optimum Tidal Volume from the Breathing Frequency, Body Weight and Sex of the Patient.



21

Low TV causes Atelectasis

- Concern that atelectasis developed at low the tidal volumes (without PEEP) used for longer periods led to the practice of using 10-15ml/kg tidal volume;
  - Bendixen, H.H., J. Hedley-Whyte, and M.B. Laver, *Impaired Oxygenation in Surgical Patients During General Anesthesia with Controlled Ventilation. A Concept of Atelectasis.* N Engl J Med, 1963. **269**: p. 991-6
- No mention of PEEP

22

The Lancet · Saturday 12 August 1967

ACUTE RESPIRATORY DISTRESS IN ADULTS

DAVID G. ASHBAUGH

of lung compliance, and diffuse alveolar infiltration seen on chest X-ray.

No patient had a previous history of respiratory failure. 1 patient gave a history of mild asthma since childhood but had

A new phenomena of hypoxemia and non cardiogenic pulmonary oedema in critically ill patients.

Ashbaugh DG, Bigelow DB, PettyTL, Levine BE

Lancet. 1967 Aug 12;2(7511):319-23.

tachypnœa, hypoxæmia, and loss of compliance after a variety of stimuli; the syndrome did not respond to usual and ordinary methods of respiratory therapy. The clinical and pathological features closely resembled those seen in infants with respiratory distress and to conditions in congestive atelectasis and postperfusion lung. The theoretical relationship of this syndrome to alveolar surface active agent is postulated. Positive end-expiratory pressure was most helpful in combating atelectasis and hypoxæmia. Corticosteroids appeared to have value in the treatment of patients with fat-embolism and possibly viral pneumonia.

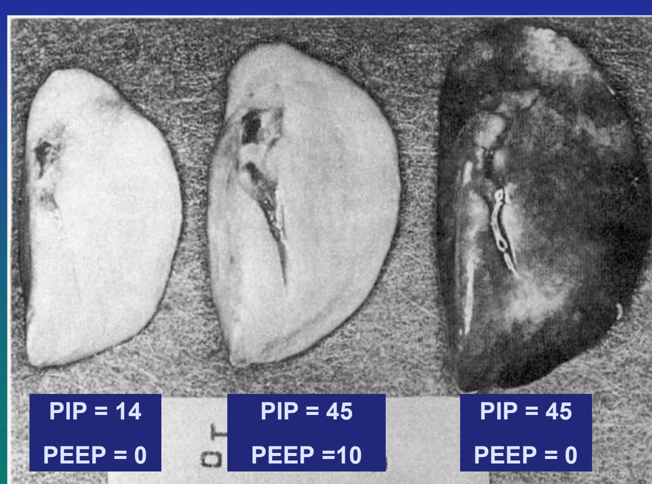
FREEBAIRN

TABLE I—ACUTE RESPIRATORY DISTRESS

Case	Age (yr.)	Sex	Illness	Onset of acute respiratory distress (hr. after illness)	Possible contributory factors: Hypotension	Acidosis	Fluid overload
1	29	M	Multiple trauma; lung contusion	8	++	++	+++ 7500 ml.
2	19	F	Multiple trauma; lung laceration and contusion	1	+++	++	+++ 3000 ml.

23

Ventilator Induced Lung Injury



Webb&Tierney ARRD 1974;110;556

24

Lowered TV & Plateau Pressures

- First cases of intentional permissive hypercarbia/ hypoventilation in Christchurch Intensive Care, NZ.
- Described limited tidal volumes , limited airway pressures to protect against barotrauma /volutrauma in ARDS , with apparent survival benefits.

Hickling K, et al . Low mortality associated with low volume pressure limited ventilation with permissive hypercapnia in severe adult respiratory distress syndrome Intensive Care Medicine . 1990; 16, 372-7

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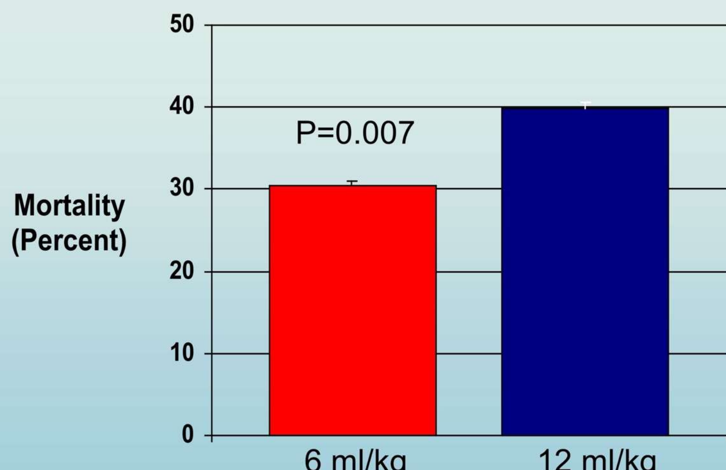
ck to the future

ARDSnet Mortality Prior to Hospital Discharge



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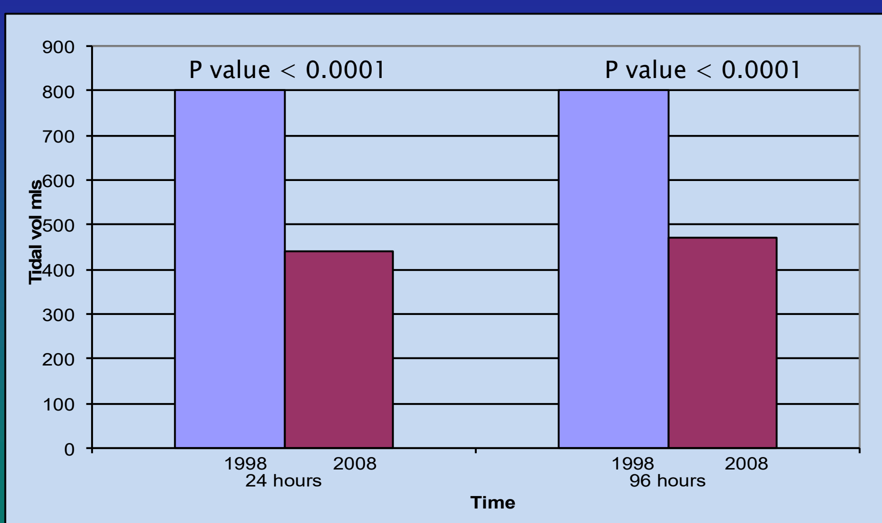
Lung Protective Ventilation

Recommended that patients be ventilated with low tidal volumes (4-8 mL/kg of predicted body weight)

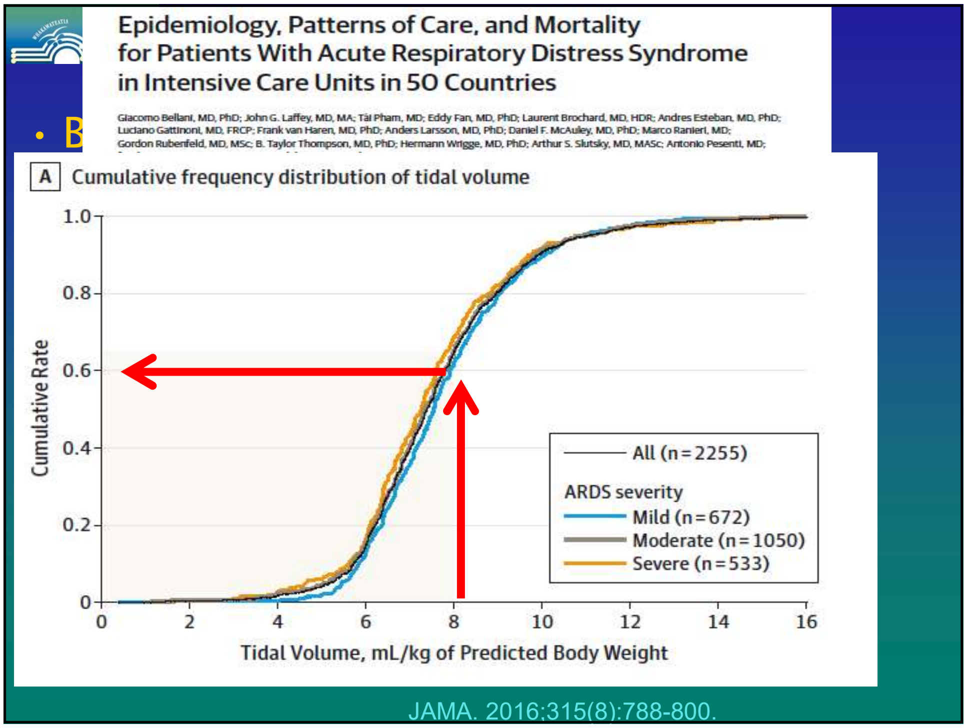
27

Tidal volumes



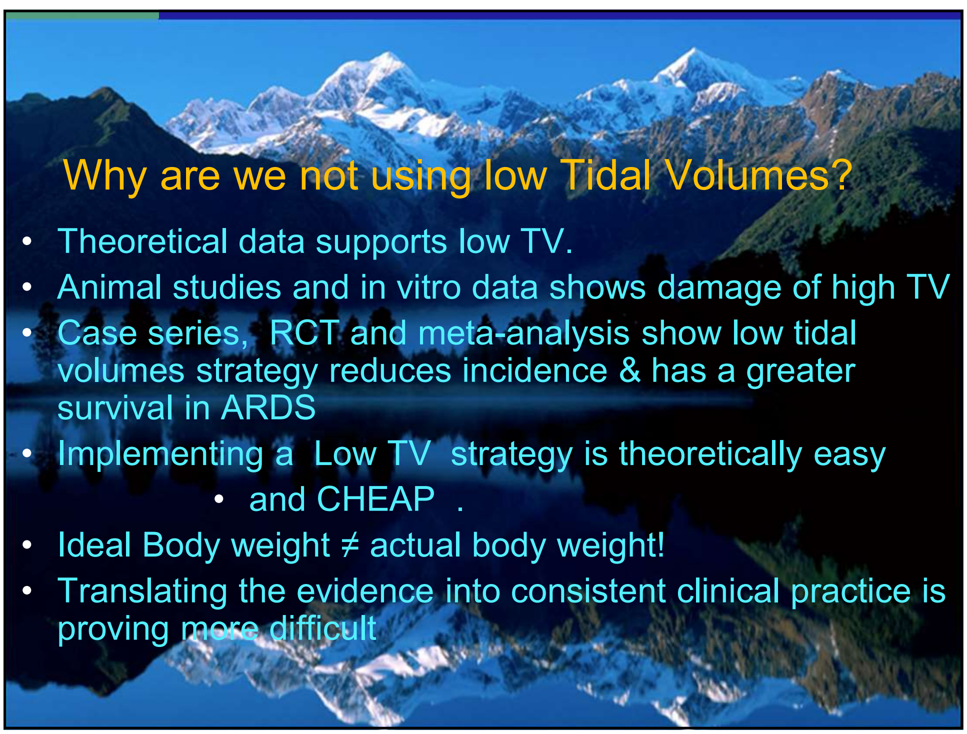
More R, Ward E, Bennett F, Trent L, **Freebairn R.** An Audit of Changes in Ventilatory Practice over the Last Decade. Crit Care Shock 2010. 13, 1, 34-35

28



Epidemiology, Patterns of Care, and Mortality for Patients With Acute Respiratory Distress Syndrome in Intensive Care Units in 50 Countries
Giacomo Bellani, MD, PhD; John G. Laffey, MD, MA; Tài Pham, MD; Eddy Fan, MD, PhD; Laurent Brochard, MD, HDR; Andres Esteban, MD, PhD; Luciano Gattinoni, MD, FRCP; Frank van Haren, MD, PhD; Anders Larsson, MD, PhD; Daniel F. McAuley, MD, PhD; Marco Ranieri, MD; Gordon Rubenfeld, MD, MSc; B. Taylor Thompson, MD, PhD; Hermann Wrigge, MD, PhD; Arthur S. Slutsky, MD, MASc; Antonio Pesenti, MD;
A Cumulative frequency distribution of tidal volume
Cumulative Rate
1.0
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
14
16
Tidal Volume, mL/kg of Predicted Body Weight
All (n = 2255)
ARDS severity
Mild (n = 672)
Moderate (n = 1050)
Severe (n = 533)
JAMA. 2016;315(8):788-800.

29



Why are we not using low Tidal Volumes?
• Theoretical data supports low TV.
• Animal studies and in vitro data shows damage of high TV
• Case series, RCT and meta-analysis show low tidal volumes strategy reduces incidence & has a greater survival in ARDS
• Implementing a Low TV strategy is theoretically easy
• and CHEAP .
• Ideal Body weight ≠ actual body weight!
• Translating the evidence into consistent clinical practice is proving more difficult

30

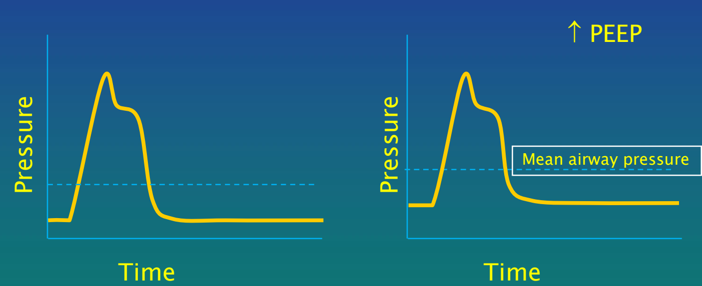
Lung Protective Ventilation

Recommended that patients be ventilated with low tidal volumes (4-8 mL/kg of predicted body weight)

Lung protective ventilation includes the use of 'high' PEEP but this has a less defined benefit in ARDS management

31

Mean airway pressure



32

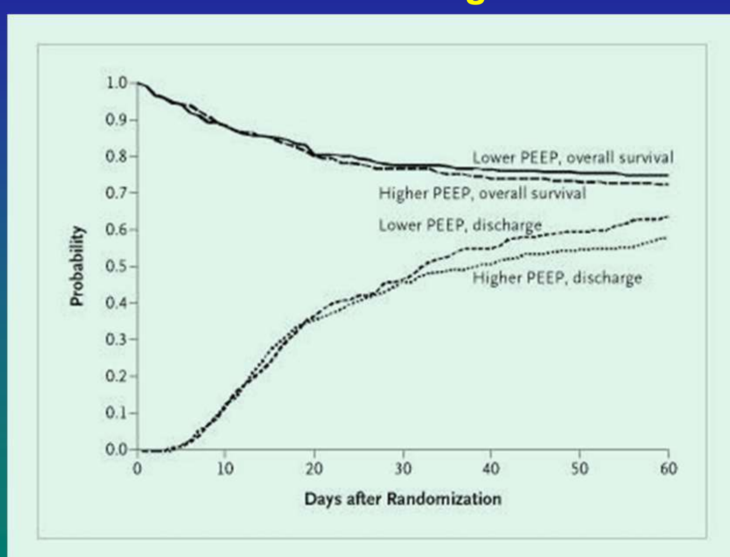
No single PEEP strategy has proven to be ideal,

Trials have outlined various PEEP titration strategies

“Consensus” surrounding the idea of limiting over-distention of lung parenchyma while providing maximum number of open alveoli.

33

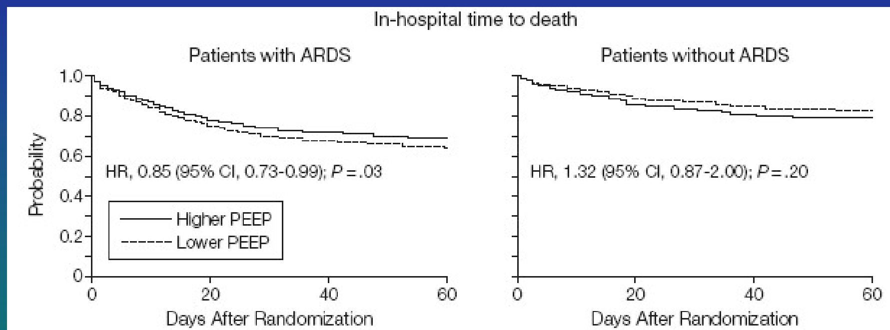
Ventilation with Lower or Higher Levels of PEEP Survival to Discharge Home



The National Heart, Lung, and Blood Institute ARDS Clinical Trials Network, N Engl J Med 2004;351:327-336

34

Effect of PEEP on mortality in ARDS; Meta- analysis



Briel, M et al Higher vs Lower Positive End-Expiratory Pressure in Patients With Acute Lung Injury and Acute Respiratory Distress Syndrome
JAMA: :2010 vol:303 iss:9 pg:865 -873

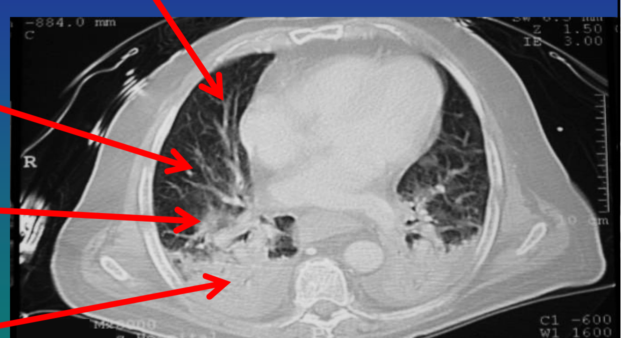
35

"Ideal PEEP" is a compromise

Open @any PEEP
Over distended at TV

Open @Low PEEP
Distended @ **High** PEEP

Collapsed @Low PEEP
Open @ **Mid** PEEP
Tidal recruitment



Collapsed @Mid PEEP
Open @ **High** PEEP
Tidal recruitment ?

36

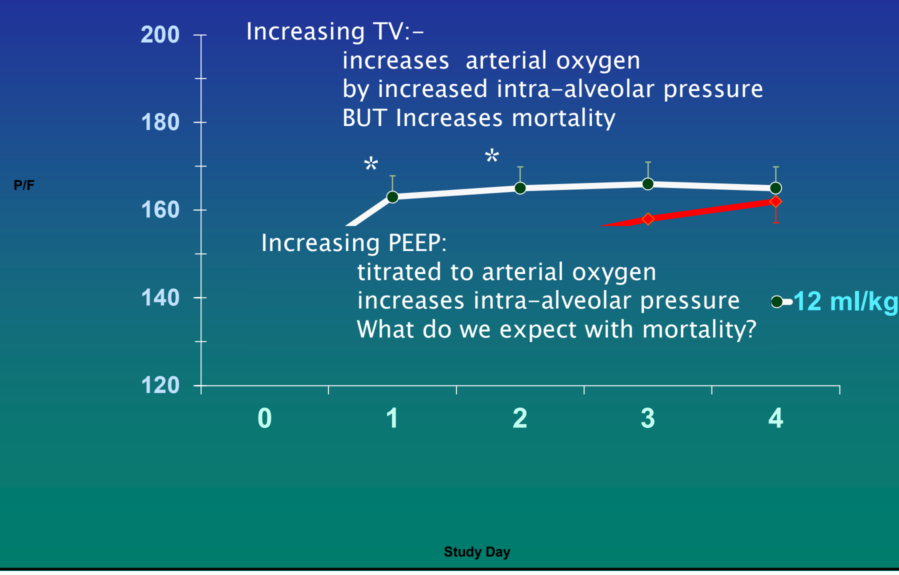
To increase oxygenation

- Oxygen in
  - □ □ FIO2
  - □ □ mean alveolar pressure
    - TV
    - Increased Inspiratory time PAUSE/I:E/
    - PEEP
  - PEEP
    - Re-open alveoli and □ shunt
  - RECRUITMENT
    - Re-open alveoli and □ shunt
  - Prone Positioning

- BUT
- Increasing
  - TV
  - PAUSE
  - Inspiratory time
- Decreases Venous return
  - Decrease Cardiac Output
- Potential for
  - over distension
  - gas trapping
  - Increased shear stress

37

ARDSnet PaO_2 / FiO_2



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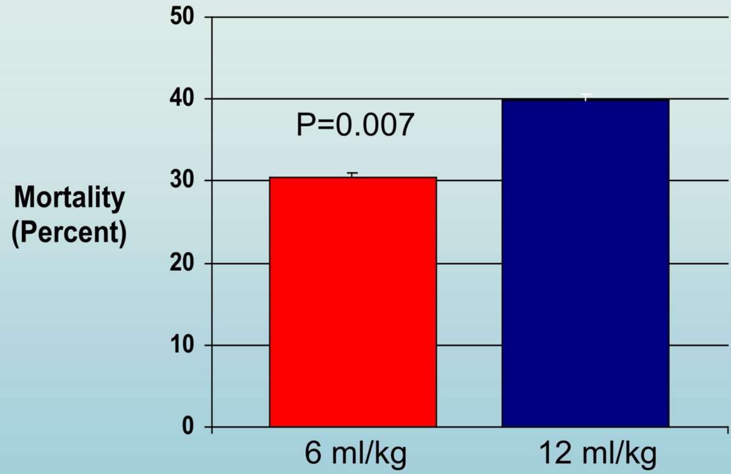
ck to the future

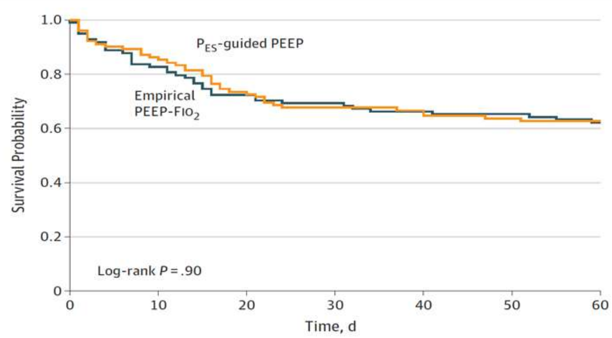
ARDSnet Mortality Prior to Hospital Discharge



FREEBAIRN

Effect of an Esophageal Pressure-Guided PEEP Titration Strategy vs an Empirical High PEEP-FIO_2 Strategy in ARDS

Figure 3. Kaplan-Meier Survival Analysis Through Day 60

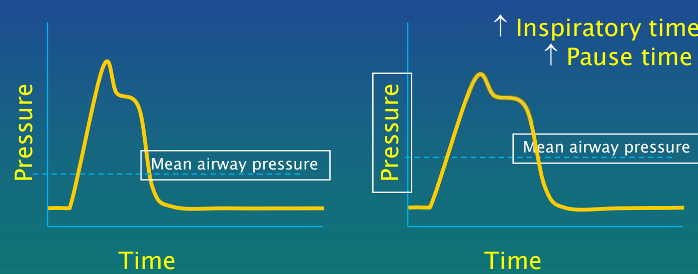


No. at risk	0	10	20	30	40	50	60
P_{ES}-guided PEEP	102	88	75	68	67	64	63
Empirical PEEP-FIO_2	98	81	71	68	65	64	61

Beitler, J.R et al Effect of Titrating Positive End-Expiratory Pressure (PEEP) with an Esophageal Pressure-Guided Strategy vs an Empirical High PEEP-FiO2 Strategy on Death and Days Free from Mechanical Ventilation among Patients with Acute Respiratory Distress Syndrome: A Randomized Clinical Trial (2019) JAMA , 321 (9), pp. 846-857.

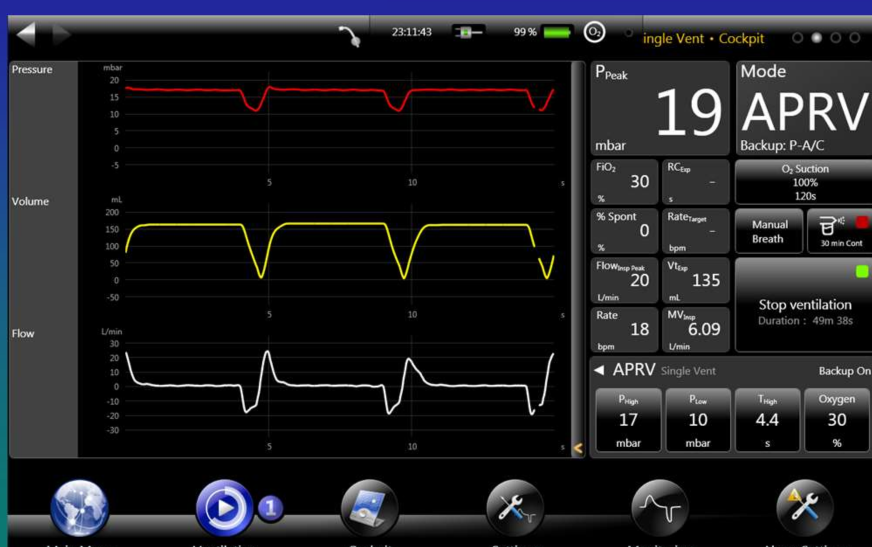
Mean airway pressure

Increase the inspiratory profile



Increases redistribution to alveolar sacs with long time constants
those with higher resistance and higher compliance

41



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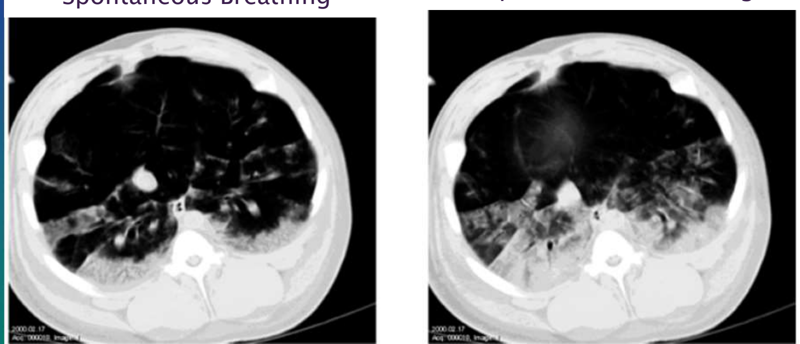
APRV- and Spontaneous Breathing

APRV/ Bi PAP with Spontaneous Breathing

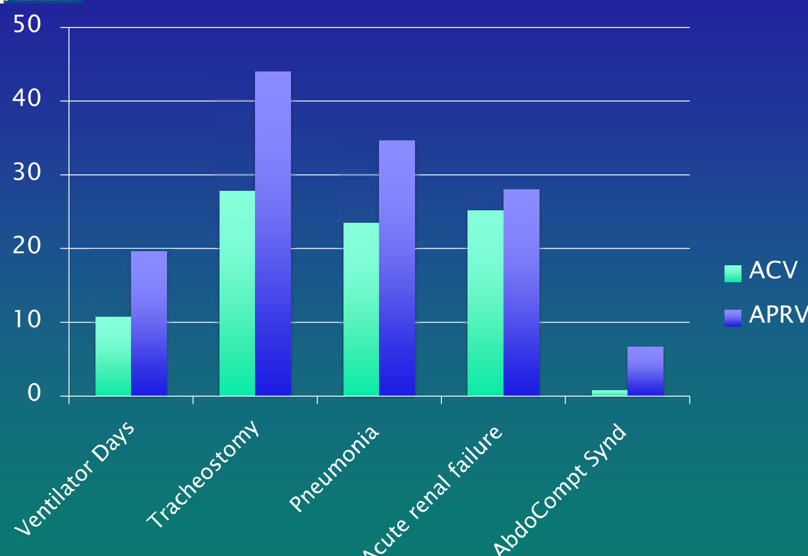
APRV/ Bi PAP without Spontaneous Breathing



Critical Care 2004, 8:492-497 (DOI 10.1186/cc2919)

43

ACV v APRV in Trauma



Compared to conventional ventilation, airway pressure release ventilation may increase ventilator days in trauma patients

J Trauma Acute Care Surg. 2012;73: 507Y510

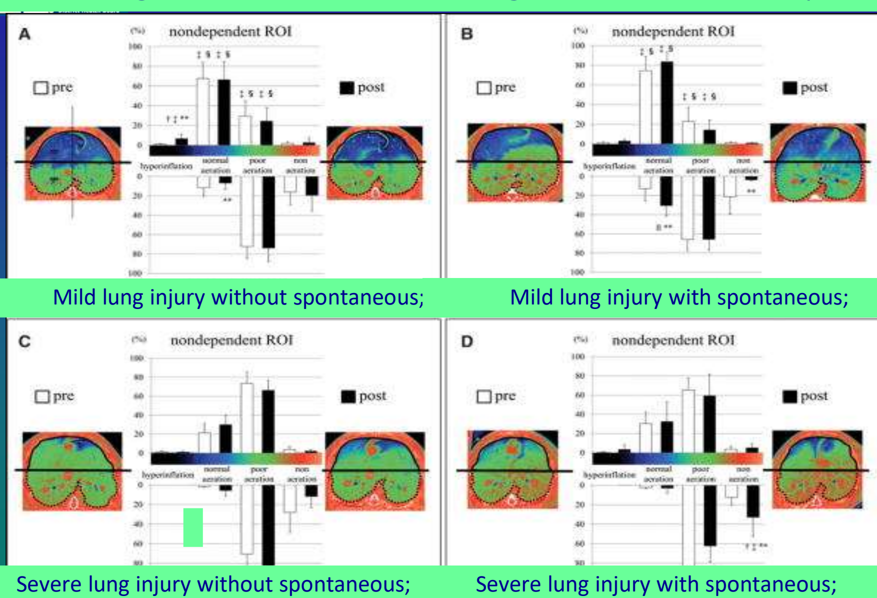
44

To suppress or support spontaneous breathing?

- …….. the authors suggest the use of techniques of mechanical ventilatory support that **maintain, rather than suppress, spontaneous ventilatory effort,** especially in patients with severe pulmonary dysfunction.
  - Putensen, C, Hering, R, Muders, T and Wrigge, H **Assisted breathing is better in acute respiratory failure.** Curr Opin Crit Care 11:1, 63-8 (2005)
- ……**The use of NMBAs in the early phase of ARDS could reinforce the beneficial effects of a lung-protective ventilation.** In this context, the effect of NMBAs on the outcome of ARDS patients must be evaluated.
  - Forel, JM, Roch, A and Papazian, L**Paralytics in critical care: not always the bad guy.** Curr Opin Crit Care 15:1, 59-66 (2009)

45

. Regional distribution of lung aeration and collapse

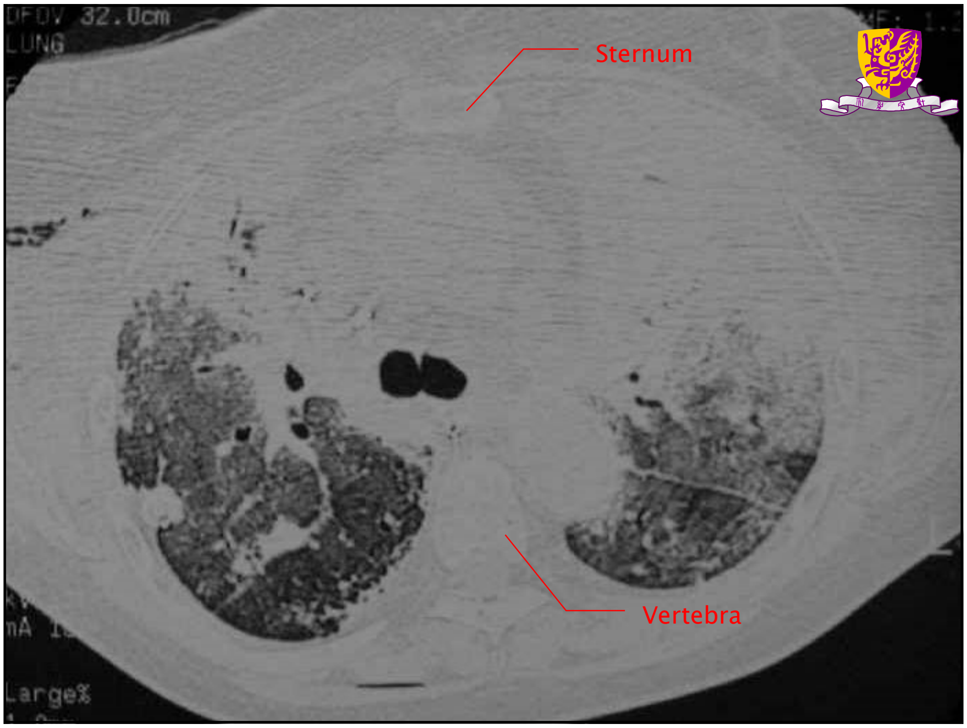


Mild lung injury without spontaneous; Mild lung injury with spontaneous;

Severe lung injury without spontaneous; Severe lung injury with spontaneous;

Yoshida, T et al . **The Comparison of Spontaneous Breathing and Muscle Paralysis in Two Different Severities of Experimental Lung Injury*.** Critical Care Medicine. 41(2):536-545, February 2013.

46



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Neuromuscular blockade

- potentially benefit patients with ARDS by reducing lung injury caused by patient-ventilator dys-synchrony and strong spontaneous respiratory effort.

The ACURASYS trial revealed that NMB improved 90-day mortality & increased ventilator free days

In contrast the ROSE trial revealed no significant endpoint difference.

Meta-analysis : NMB Patients were

- less physically active
- had increased cardiovascular events.
- reduced risk of barotrauma
- improved oxygenation
- without any worsening of ICU acquired weakness

48

Pressure v Volume Modes

- With NMJB
  - Volume Assist/Control or SIMV (vol) = CMV
  - Pressure Assist/Control/BiPAP /APRV or SIMV (press) = PCV
    - Some Modes titrate pressure to compliance& resistance (ASV, PRVC)

- If NMBA increases respiratory compliance
  - addition of NMJB in volume mode may decrease alveolar pressures.
  - addition of NMJB in Pressure controlled mode may decrease airway pressures for the same volume .
    - larger tidal volumes,
    - increasing alveolar distension.

NMBA with pressure ventilation has the potential for **increased** ventilator-associated lung injury through volutrauma.

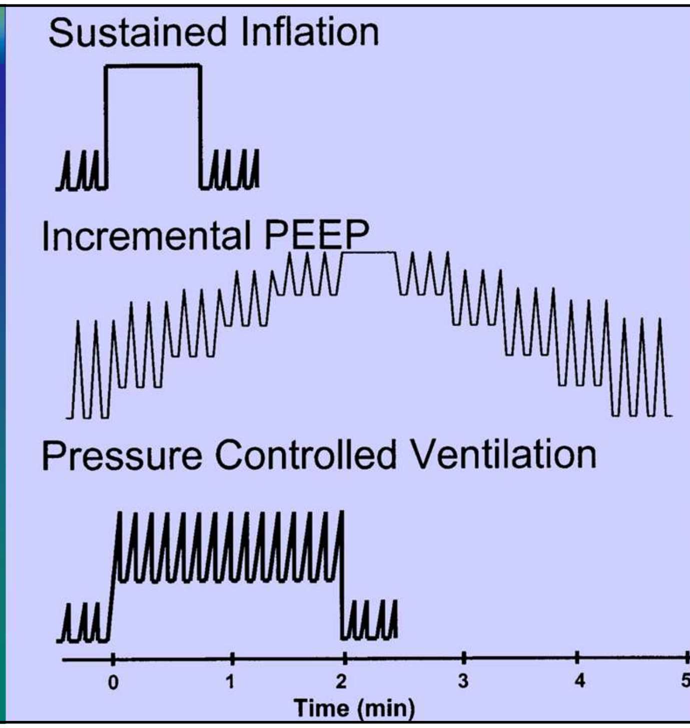
Freebairn R "How relaxed should we be about ARDS". Crit Care Med. 2004 Jan;32 (1):296.

49

How do we increase oxygenation

- Oxygen in
  - □ □ FiO2
  - □ □ mean alveolar pressure
    - TV
    - Increased Inspiratory time PAUSE/I:E/
    - PEEP
  - PEEP
    - Re-open alveoli and □ shunt
  - RECRUITMENT
    - Re-open alveoli and □ shunt
  - Prone Positioning

50



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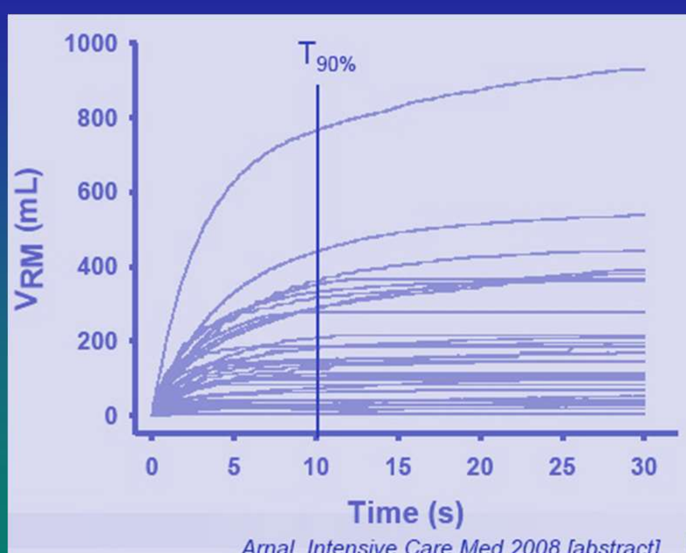
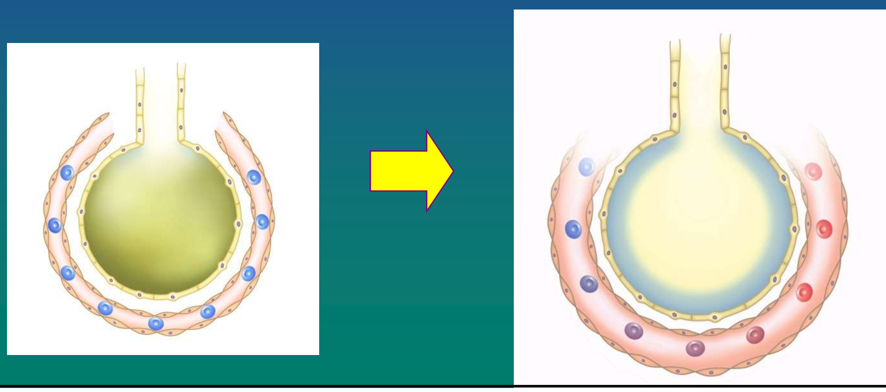
How long ??



52

The Recruitment paradox

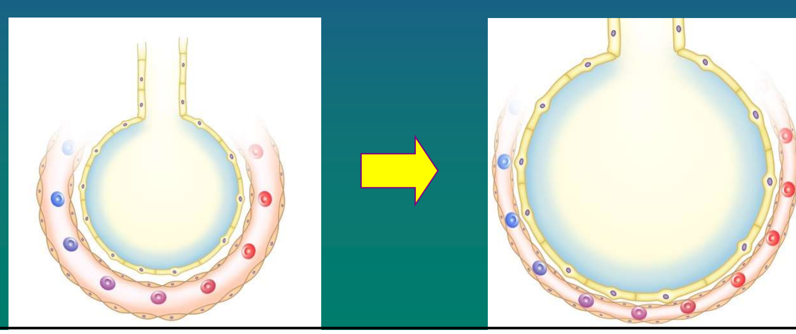
- Increased pressure will give increased volume
- Assumption : increased volume is "reopened alveoli"



53

The Recruitment paradox

- Increased pressure will give increased volume
- Assumption : increased volume is "reopened alveoli"
- Possibly over distended "healthy" alveoli



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Recruitability?

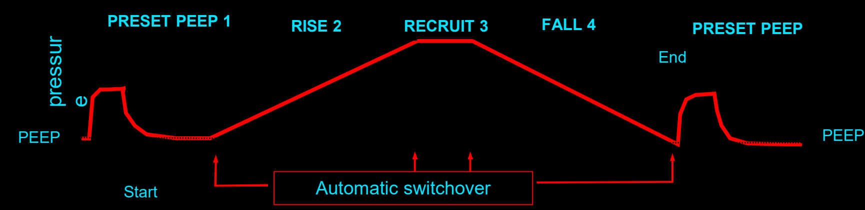
- Increased EELV may
  - not be recruitment of previously nonaerated lung units,
  - But further distension of previously open lung units.
  - While EELV alone may not be sufficient to assess PEEP response, identifying recruited volume created by additional PEEP have more relevance. EELV combined with measurement of compliance may be useful

- **Freebairn R,** Mistry R, Park M. Positive End Expiratory Pressure. In: Freebairn R, Kulkarni A, editors. Evidence Based Core topics in Critical Care Medicine 2019. 1. New Delhi, India: JAYPEE BROTHERS MEDICAL PUBLISHERS; 2019. p. 303-10
- Chiumello, D., et al (2016). Lung recruitment assessed by respiratory mechanics and computed tomography in patients with acute respiratory distress syndrome: What is the relationship? *American Journal of Respiratory and Critical Care Medicine, 193*(11), 1254-1263.

- "recruitability may be important
  - assessing the severity of ARDS,
  - planning recruitment maneuvers
  - setting adequate PEEP levels

- Unclear which " recruitment tool is best.

Recruitment Tool (IMT) : 4 phases



Phase 1: Prolonged expiration to a preset P-start (current PEEP)

Phase 2: Linear pressure increase P-start to P-Top(3cmH20/sec)

Phase 3: Keep pressure at P-top "RECRUIT time" period

Phase 4: Linear pressure decrease from P-top to the preset end PEEP

57

IMT "Bellavista" Recruitment tool.

58

PV curve Recruitment

24 Patients , All with severe ARDS
Adverse Events:
- Hypotension 7
- Bradycardia 3
- Pneumothorax/ pneumomediastinum 0
- Aborted 3 (35, 35, 45, second s)

	Prior	1minute	5 minutes	30 minutes
Oxygen sat	88	86	93	92
MAP	70	64	72	74
PEEP Change	0	0	-2	-3
FiO2	0.6	0.6	0.55	0.5
Vol Recruited	0	440 ml		

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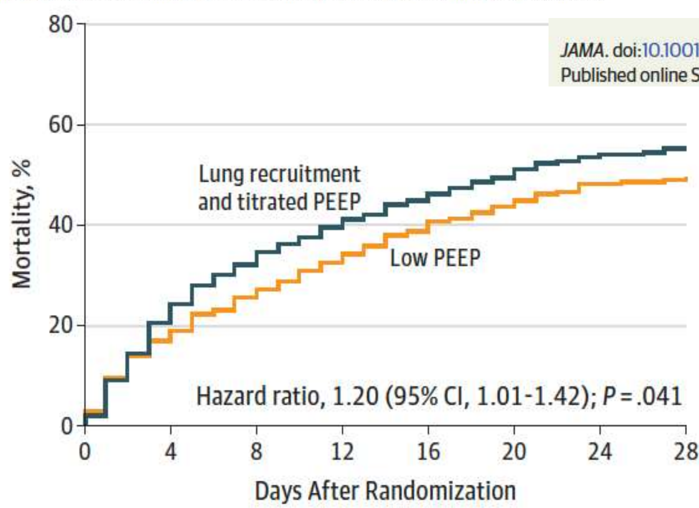
JAMA | Original Investigation | CARING FOR THE CRITICALLY ILL PATIENT

Effect of Lung Recruitment and Titrated Positive End-Expiratory Pressure (PEEP) vs Low PEEP on Mortality in Patients With Acute Respiratory Distress Syndrome
A Randomized Clinical Trial

Writing Group for the Alveolar Recruitment for Acute Respiratory Distress Syndrome Trial (ART) Investigators

JAMA. doi:10.1001/jama.2017.14171
Published online September 27, 2017.



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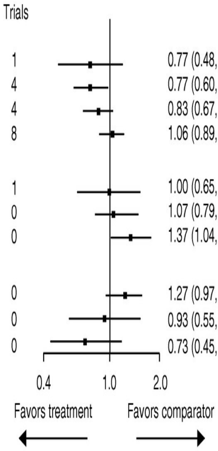
	Direct comparisons		Network Risk Ratio (95% CrI)	Absolute risk difference (95% CrI)	Posterior probabilities			Certainty
	Patients	Trials			RR < 1.0	RR > 1.0	ARR > 1%	
vs. Lower PEEP strategy								
Pes-guided	49	1	0.77 (0.48, 1.22)	−0.09 (−0.21, 0.09)	0.87	0.13	0.84	Moderate
Higher PEEP without LRM	1,162	4	0.77 (0.60, 0.96)	−0.09 (−0.16, −0.01)	0.99	0.01	0.98	High
Higher PEEP with brief LRM	1,335	4	0.83 (0.67, 1.02)	−0.07 (−0.13, 0.01)	0.96	0.04	0.94	Moderate
Higher PEEP with prolonged LRM	1,900	8	1.06 (0.89, 1.22)	0.02 (−0.04, 0.09)	0.23	0.77	0.15	Low
vs. Higher PEEP without LRM strategy								
Pes-guided	200	1	1.00 (0.65, 1.54)	0.00 (−0.11, 0.16)	0.50	0.50	0.44	Moderate
Higher PEEP with brief LRM	0	0	1.07 (0.79, 1.48)	0.02 (−0.08, 0.12)	0.32	0.68	0.25	Low
Higher PEEP with prolonged LRM	0	0	1.37 (1.04, 1.81)	0.11 (0.01, 0.21)	0.01	0.99	0.01	Moderate
Additional comparisons								
Higher PEEP with prolonged vs. brief LRM	0	0	1.27 (0.97, 1.64)	0.09 (−0.01, 0.18)	0.04	0.96	0.03	Low
Pes-guided vs. Higher PEEP with brief LRM	0	0	0.93 (0.55, 1.54)	−0.02 (−0.16, 0.17)	0.61	0.39	0.57	Low
Pes-guided vs. Higher PEEP with prolonged LRM	0	0	0.73 (0.45, 1.19)	−0.11 (−0.25, 0.08)	0.90	0.10	0.88	Low



Network Risk Ratio (95% CrI)

Am J Respir Crit Care Med, 2022

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expand collapsed alveoli,

allowing for better gas exchange.

enhance lung compliance and improve gas exchange,

impact on patient outcomes is not well defined.

62

How do we increase oxygenation

- Oxygen in
  - □ □ FIO2
  - □ □ mean alveolar pressure
    - TV
    - Increased Inspiratory time PAUSE/I:E/
    - PEEP
  - PEEP
    - Re-open alveoli and □ shunt
  - RECRUITMENT
    - Re-open alveoli and □ shunt
  - Prone Positioning

63

Prone positioning

- Various randomized, controlled trials a meta-analysis showed that prone ventilation can improve mortality of patients with severe ARDS.
- Improved survival is not mediated through improved oxygenation but rather due to a more even distribution of volume and distention forces across the lung, leading to a reduction of ventilator-induced lung injury .
- However in LUNGSAFE prone positioning of of ARDS patients was 16.3%
- Factors associated with low implementation of prone ventilation include: clinician recognition of ARDS,
  - Logistical difficulties,
  - fear of complications,
  - under-recognition of hypoxemia

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How do we increase oxygenation

- Oxygen in
  - FIO2
  - mean alveolar pressure
    - TV
    - Increased Inspiratory time PAUSE/I:E/
    - PEEP
  - PEEP
    - Re-open alveoli and shunt
  - RECRUITMENT
    - Re-open alveoli and shunt
  - Prone Positioning

The NEW ENGLAND JOURNAL of MEDICINE

Driving Pressure and Survival in the Acute Respiratory Distress Syndrome

Marcelo B.P. Amato, M.D., Maureen O. Meade, M.D., Arthur S. Slutsky, M.D., Laurent Brochard, M.D., Eduardo L.V. Costa, M.D., David A. Schoenfeld, Ph.D., Thomas E. Stewart, M.D., Matthias Briel, M.D., Daniel Talmor, M.D., M.P.H., Alain Mercat, M.D., Jean-Christophe M. Richard, M.D., Carlos R.R. Carvalho, M.D., and Roy G. Brower, M.D.

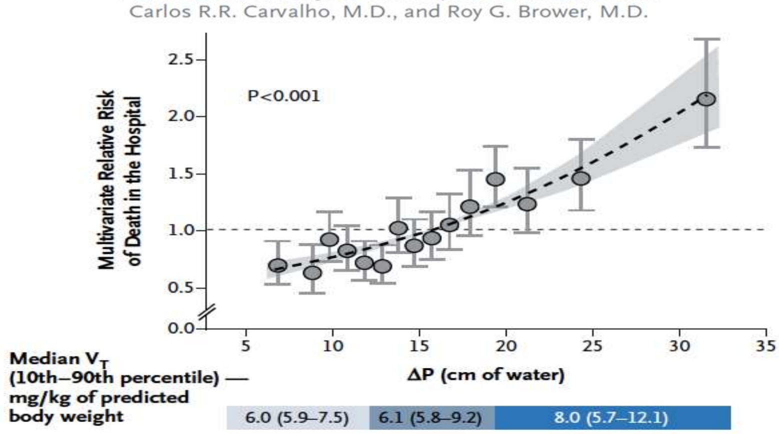
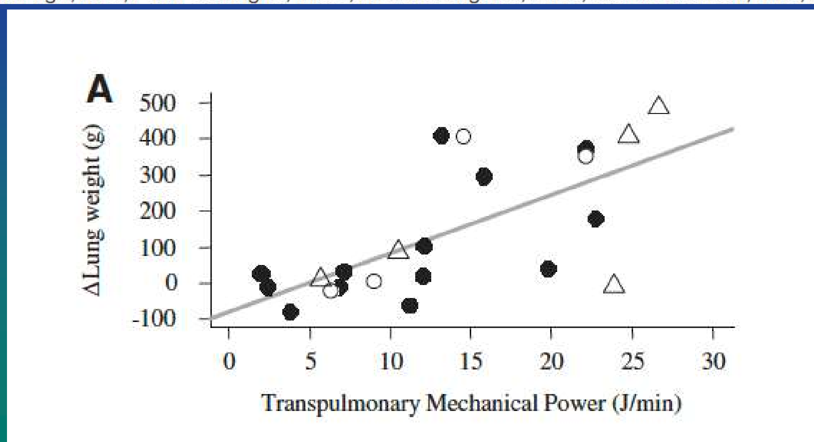


Figure 2. Relative Risk of Death in the Hospital versus ΔP in the Combined Cohort after Multivariate Adjustment.

Mechanical Power and Development of Ventilator-induced Lung Injury

Massimo Cressoni, M.D., Miriam Gotti, M.D., Chiara Chiurazzi, M.D., Dario Massari, M.D., Ilaria Algieri, M.D., Martina Amini, M.D., Antonio Cammaroto, M.D., Matteo Brioni, M.D., Claudia Montaruli, M.D., Klodiana Nikolla, M.D., Mariateresa Guanziroli, M.D., Daniele Dondossola, M.D., Stefano Gatti, M.D., Vincenza Valerio, Ph.D., Giordano Luca Vergani, M.D., Paola Pugni, M.D., Paolo Cadringher, M.Sc., Nicoletta Gagliano, Ph.D., Luciano Gattinoni, M.D., F.R.C.P.



ANESTHESIOLOGY 2016; 124:1100-8

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Power of ventilation

$$P = (E_{rs} \cdot \Delta V) + (F \cdot R_{aw}) + PEEP$$

$\times \Delta V$

$$Power_{rs} = 0{,}098 \cdot RR \cdot \left\{ \Delta V^2 \cdot \left[\frac{1}{2} \cdot E_{rs} + RR \cdot \frac{(1 + I:E)}{60 \cdot I:E} \cdot R_{aw} \right] + \Delta V \cdot PEEP \right\}$$

Distend the lung | Move the gas | Keep open

$\frac{\text{n breaths}}{\text{time}}$ × ENERGY to ...

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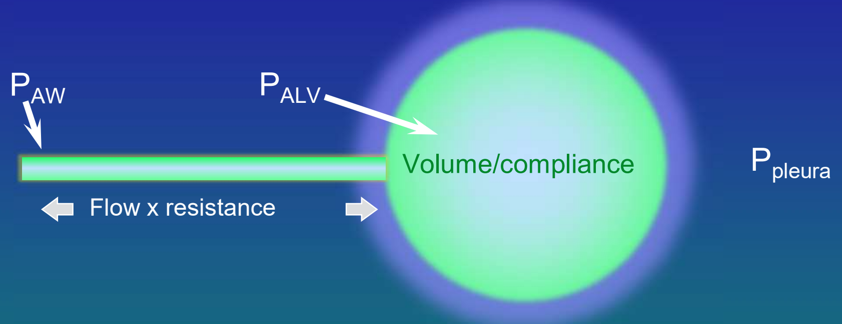
Alveolar and Trans-alveolar Pressure



$$P_{aw} = \text{Flow} \times \text{Resistance} + \frac{\text{Volume}}{\text{Compliance}} + \text{PEEP}$$

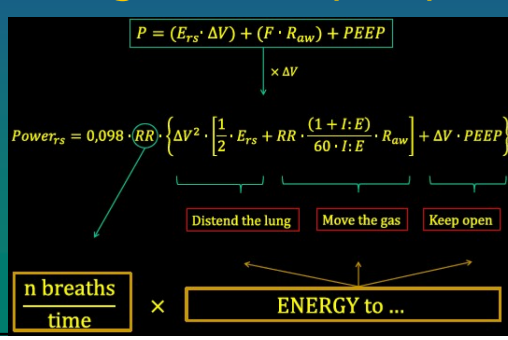
$$P_{alv} = \frac{\text{Volume}}{\text{Compliance}} + \text{PEEP}$$

$$P_{trans\ alv} = P_{alv} - P_{pleural}$$

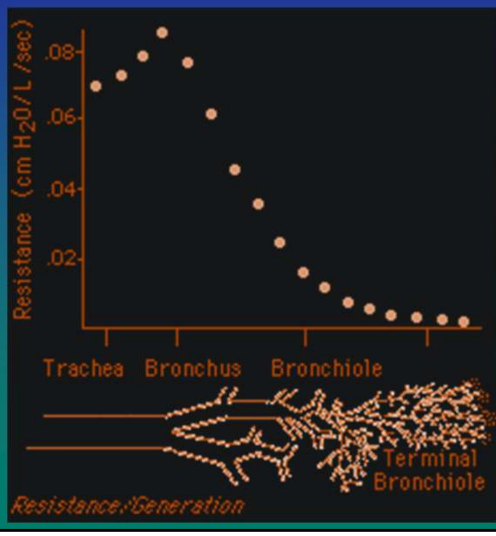
Power and MV

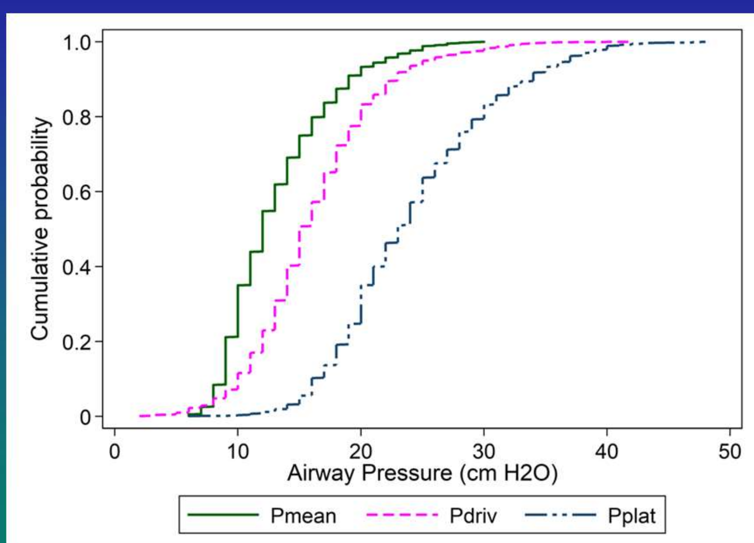
MV = TV x RR

- Increased RR increases flow for same TV
- Increased TV Increases flow and alveoli distension
- Differing effects upon power



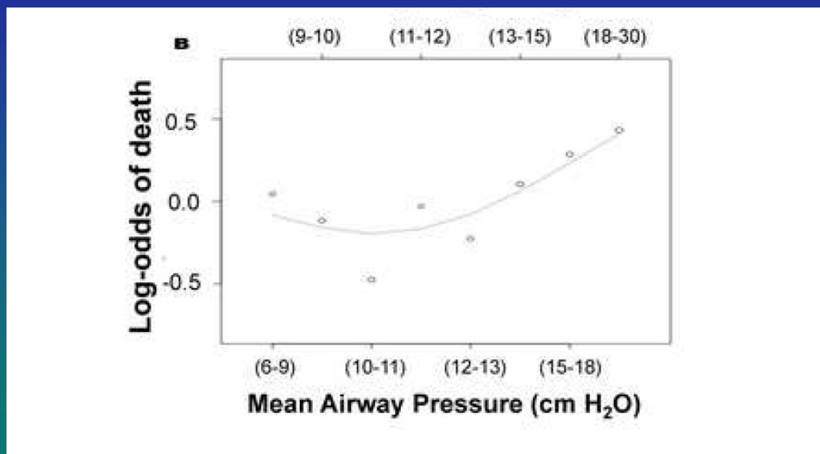
Flow, resistance and the lungs





- Sahetya SK, Wu TD, Morgan B, et al: Mean Airway Pressure As a Predictor of 90-Day Mortality in Mechanically Ventilated Patients. Crit Care Med 2020; 48:688-695

MAWP and Mortality



- Sahetya SK, Wu TD, Morgan B, et al: Mean Airway Pressure As a Predictor of 90-Day Mortality in Mechanically Ventilated Patients. Crit Care Med 2020; 48:688-695

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Mean Airway pressure

- MAWP is associated (in some studies) with outcome in ARDS
- High MAWP = increased mortality
  - Sahetya SK, Wu TD, Morgan B, et al: Mean Airway Pressure As a Predictor of 90-Day Mortality in Mechanically Ventilated Patients. Crit Care Med 2020; 48:688-695
- MAWP generally reflects Mean alveolar pressure
- But Relationship altered by
  - Manipulation of I:E , flow rates pause time and
  - Differential lung volumes ie large hysteresis , and PEEP may alter MAWP to Malv P relationship.

– Easy to measure

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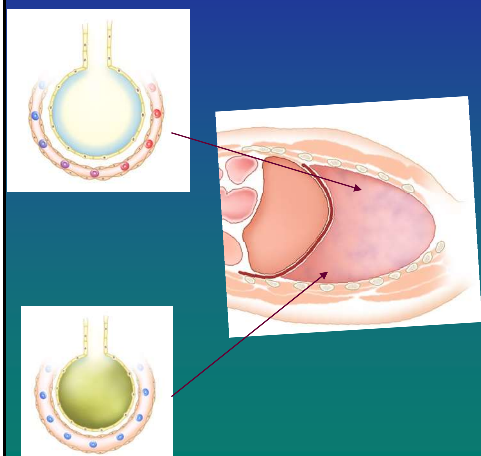
EARLY Prone ventilation



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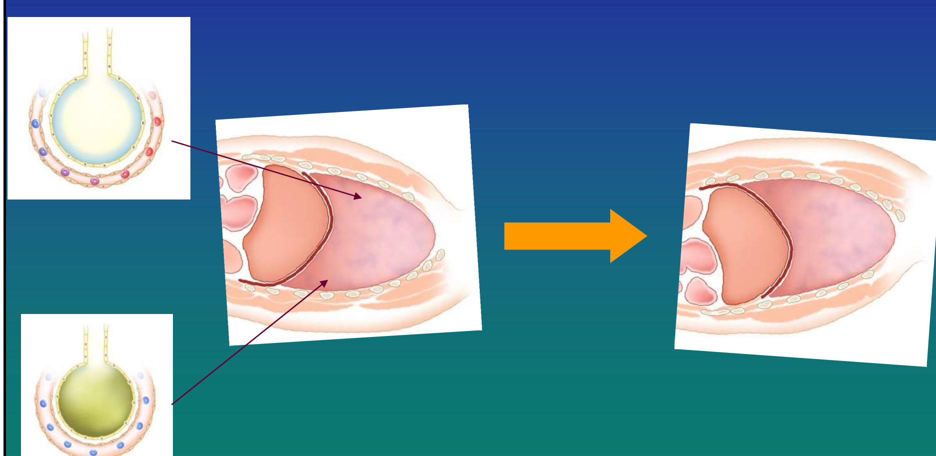
Prone ventilation



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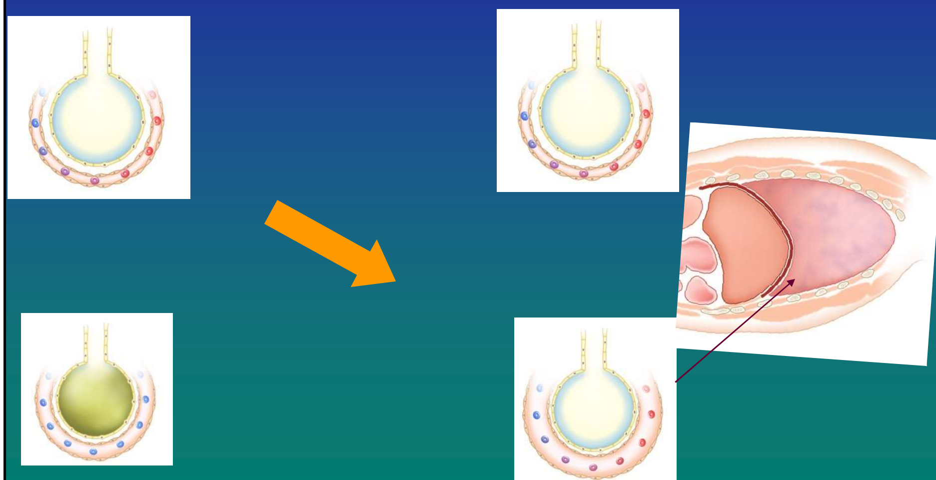
Prone ventilation



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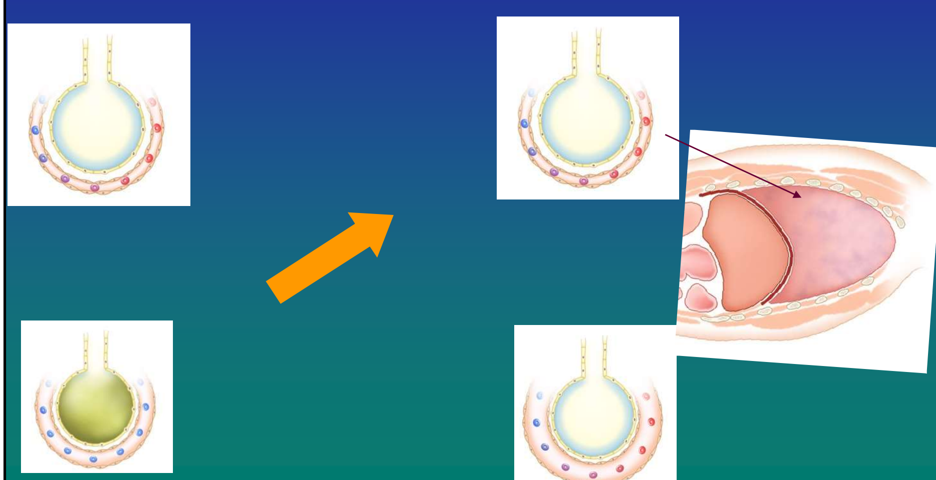
Prone ventilation



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Preparation

- Criteria
  - PaO_2/FiO_2 ratio ≤ 150mmHg (20kPa)
  - PEEP ≥ 5cmH_2O
  - FiO_2 ≥ 0.6
- Haemodynamically stable

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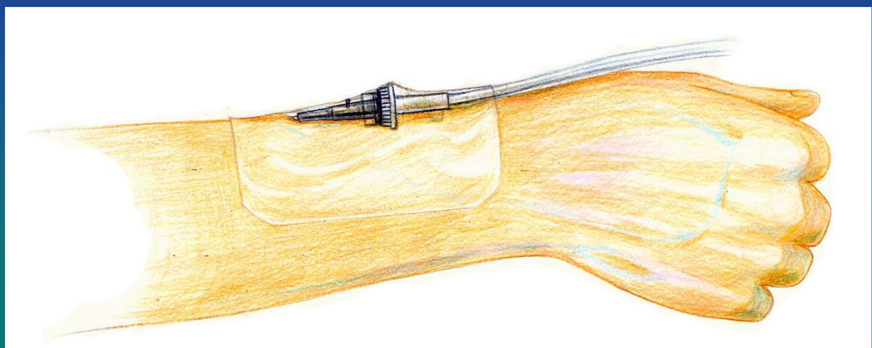
Venous access secure



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Intubation drugs/equipment

81

Preparation

- Prepare padding to prevent pressure sores in prone position
- Staff
  - Someone who can re-intubate to look after head, neck & ETT
  - 4 other staff

82

Procedure

- Clamp tube or take care to prevent disconnection of ventilator
  - Prevent collapse

Duration

- Most responders show an improvement in gas exchange within a few hours
- Prone for 16h then supine for at least 4h

Summary

- Low tidal volume, low pressure
- Open lung approach makes "sense"
  - Recruitment
  - High PEEP
- Minimize FiO_2
- Early prone ventilation in patients meeting criteria

Society	Recommendation	Strength of Recommendation	Evidence
ATS/ESICM/SCCM	Mechanical ventilation with low tidal volumes and inspiratory pressures	Strong	Moderate
	Daily prone positioning >12 h	Strong	Moderate-high
	Avoid HFOV in patients with moderate or severe ARDS	Strong	Moderate-high
	Mechanical ventilation with higher levels of PEEP for moderate or severe ARDS	Conditional	Moderate
	Recruitment maneuvers should be used	Conditional	Low-moderate
	Additional research needed to recommend use of ECMO in patients with ARDS	Not applicable	Not applicable
FICM/ICS	Mechanical ventilation with low tidal volumes (<6 mL/kg ideal body weight) and plateau pressure (<30 cm H_2O)	Strong	Moderate
	Daily prone positioning ≥12 h in patients with moderate/severe ARDS	Strong	Moderate
	Avoid HFOV	Strong	Moderate
	Conservative fluid management	Weakly in favor	Low
	Mechanical ventilation with higher levels of PEEP in patients with moderate/severe ARDS	Weakly in favor	Low
	Neuromuscular blocking agents in patients with moderate/severe ARDS	Weakly in favor	Moderate
	Use of ECMO in patients with severe ARDS	Weakly in favor	Very low

Abbreviations: ATS: American Thoracic Society; ESICM: European Society of Intensive Care Medicine; SCCM: Society of Critical Care Medicine Clinical Practice Guideline; FICM: Faculty of Intensive Care Medicine; ICS: Intensive Care Society.

- Liaqat, A.; Mason, M.;Foster, B.J.; et al.Evidence-Based Mechanical Ventilatory Strategies in ARDS. J. Clin. Med. 2022, 11, 319.

If power, volume and/ or stress are the issue

Then perhaps less ventilation
: HFNC
Permissive hypercapnia