ARDS

and

Ventilator Induced Lung Injury

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Disclosures

I have no financial conflicts of interest to disclose

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Objectives

- Explain mechanisms that lead to ventilator induced lung injury (VILI)
- Determine how to assess ventilator parameters and alter ventilator settings to minimize harmful effects of ventilation
- Discuss strategies that can be used to minimize VILI in patients with COVID-19 pneumonia

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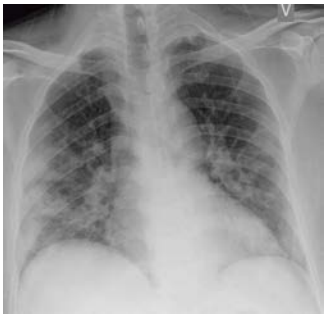
Case #1

- 39-year-old male
- Presented to ER with 72 hrs of increasing SOB, cough, fever
- Past medical history of obesity, diabetes
- Temp 102, RR 32,
- SaO_2 70% on room air



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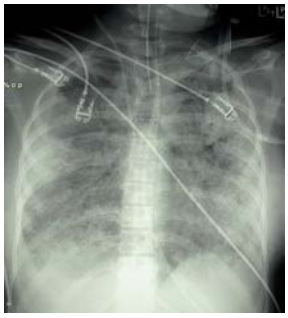
Case #1

- Started on heated high flow O_2
- Cultures sent, ATBx given
- Wbc 14, Lactate 6, Cr 1.9
- SARS CoV-2 positive
- Steroids given
- Progresses to Bilevel
- Intubation



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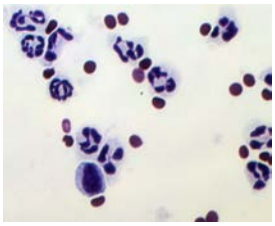
Acute Respiratory Distress Syndrome (ARDS)

- Inflammation
- Diffuse alveolar damage
- Capillary leak
- Hyaline membranes
- Impaired gas exchange



BAL specimen with profound neutrophilia

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Acute Respiratory Distress Syndrome (ARDS)

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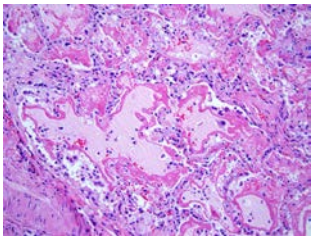

Lung tissue stained with hematoxylin and eosin

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Definition of ARDS – Berlin Criteria

Feature	Definition	Our patient
Timing		
Imaging		
Origin of Edema		
Oxygenation		

JAMA, June 20, 2012

Definition of ARDS – Berlin Criteria

Feature	Definition	Our patient
Timing	New onset of worsening respiratory symptoms within 1 week of insult	
Imaging	Bilateral opacities	
Origin of Edema	Not due to congestive heart failure or volume overload	
Oxygenation	PaO2 : FiO2 ratio ≤ 300 mm Hg • Mild: 300 ≤ P:F < 200 • Moderate: 200 ≤ P:F < 100 • Severe: P:F ≤ 100	Mortality Mild 20% Moderate 41% Severe 52%

JAMA, June 20, 2012

Definition of ARDS – Berlin Criteria

Feature	Definition	Our patient
Timing	New onset of worsening respiratory symptoms within 1 week of insult	72 hrs
Imaging	Bilateral opacities	Present
Origin of Edema	Not due to congestive heart failure or volume overload	No heart failure
Oxygenation	PaO2 : FiO2 ratio ≤ 300 mm Hg • Mild: 300 ≤ P:F < 200 • Moderate: 200 ≤ P:F < 100 • Severe: P:F ≤ 100	Blood gas: PaO2 55 on 90% Oxygen PaO2 / FiO2 = 55 / 0.9 = 61

JAMA, June 20, 2012

ARDS Management

- Treat Underlying Cause
- Ventilatory Support
- Prone Positioning
- Steroids

History of Mechanical Ventilation

- 1928 Drinker and Shaw invent the iron lung- negative pressure ventilator
- Widespread use in treatment of polio in early 20th century
- 1952 Scandinavian polio epidemic- positive pressure ventilation used

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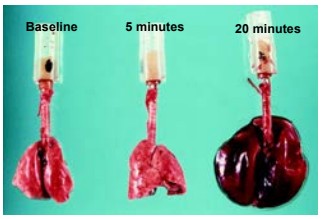
Ventilator Induced Lung Injury (VILI)

- 1974: Webb and Teirney show that MV with high pressures results in pulmonary edema
- 1985: Dreyfuss identified microcirculatory injury and increased permeability as central to VILI pathophysiology
- 1988: Animal studies show that *high lung volumes*, not pressures, are culprit in VILI

"Volutrauma"



Rat lungs ventilated with high pressures (45 cm H2O)

Dreyfus. Am J Respir Crit Care Med. 1998: 294-323.

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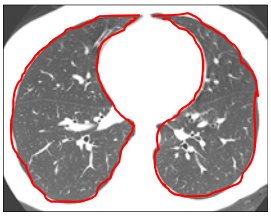
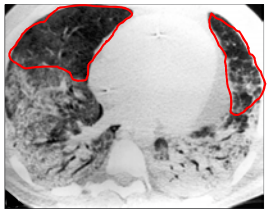
The "Baby Lung" in ARDS

Normal



ARDS



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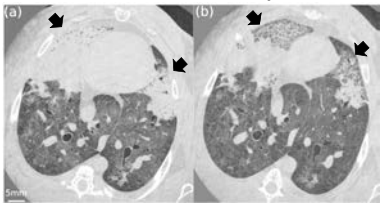
Atelectrauma

- Damage to the alveoli from repetitive opening and closing
- Often occurs near areas of consolidation
- PEEP can be used to minimize alveolar collapse

End Expiration | Inspiration



*Fardin, L. Sci Rep **11,** 4236 (2021).*

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How Can We Minimize Ventilator Induced Lung Injury?

Lung-Protective Ventilation

- ARDSNet, NEJM 2000
- Prospective multi-center randomized controlled trial
- Traditional vs low tidal volumes
- 12 ml/kg vs 6 ml/kg
- Primary outcome: alive and breathing without assistance
- Stopped early - improved survival with low tidal volumes


The New England Journal of Medicine

VENTILATION WITH LOWER TIDAL VOLUMES AS COMPARED WITH TRADITIONAL TIDAL VOLUMES FOR ACUTE LUNG INJURY AND THE ACUTE RESPIRATORY DISTRESS SYNDROME

N Engl J Med 2000;342:1301-8.

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Lung-Protective Ventilation

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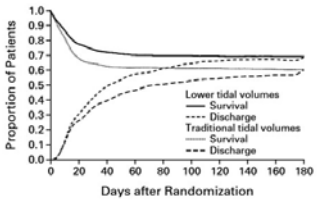
Key Result



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Key Result

TABLE 4. MAIN OUTCOME VARIABLES.*

VARIABLE	GROUP RECEIVING LOWER TIDAL VOLUMES	GROUP RECEIVING TRADITIONAL TIDAL VOLUMES	P VALUE
Death before discharge home and breathing without assistance (%)	31.0	39.8	0.007
Breathing without assistance by day 28 (%)	65.7	55.0	<0.001
No. of ventilator-free days, days 1 to 28	12±11	10±11	0.007
Barotrauma, days 1 to 28 (%)	10	11	0.43
No. of days without failure of nonpulmonary organs or systems, days 1 to 28	15±11	12±11	0.006

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PEEP

- Positive end expiratory pressure
- Pressure maintained in the airways at the end of expiration

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

FiO_2	0.7	0.8	0.9	0.9	0.9	1.0	1.0	1.0
PEEP	14 20	14 20-22	14 22	16 22	18 22	20 22	22 22	24 24

Setting up the Vent

1. Volume controlled mode (Assist Control)

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Setting up the Vent

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2. V_t = 6cc/kg ideal body weight

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Setting up the Vent

1. Volume controlled mode (Assist Control)
2. Vt = 6cc/kg ideal body weight
3. Choose rate to achieve minute ventilation

   Normal ~ 5 liters per minute

   ARDS ~ 12 – 15 liters per minute

Minute Ventilation: Volume of gas that moves in and out of the lungs in 1 minute

Minute Ventilation = respiratory rate x tidal volume

= 30 breaths / min x 0.5 Liters

= 15 Liters per minute

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Setting up the Vent

1. Volume controlled mode (Assist Control)
2. Vt = 6cc/kg ideal body weight
3. Choose rate to achieve minute ventilation
4. FiO2 100%
5. PEEP 12-16 cm H_2O

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

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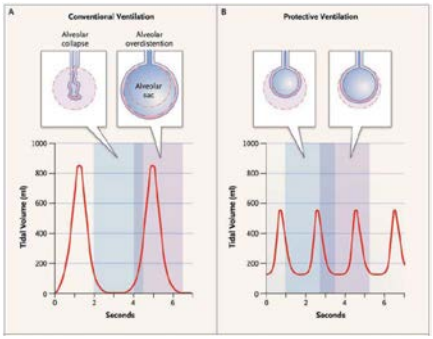
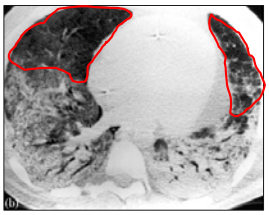
VILI

- Excess volume
- Atelectrauma

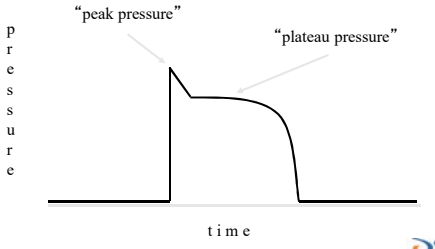


NEJM 357:1113, 2007

Can we do anything at the bedside to estimate over distention?



Plateau Pressure



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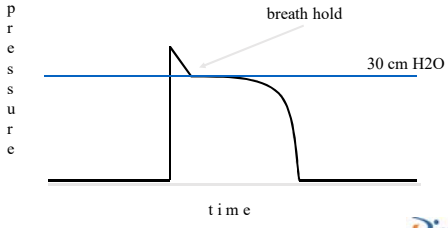
Plateau Pressure



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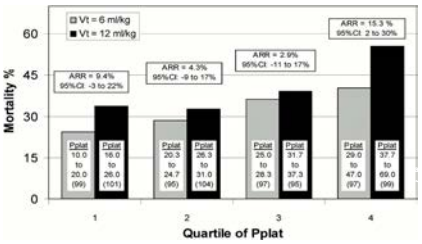
Plateau Pressure is key



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NIH NHLBI ARDS Clinical Network
Mechanical Ventilation Protocol Summary
www.ardsnet.org
revised 25Jan05

INCLUSION CRITERIA: Acute onset of
1. PaO_2/FiO_2 ≤ 300 (corrected for altitude)
2. Bilateral (patchy, diffuse, or homogeneous) infiltrates consistent with pulmonary edema
3. No clinical evidence of left atrial hypertension

PART I: VENTILATOR SETUP AND ADJUSTMENT
1. Calculate predicted body weight (PBW)
   Males = 50 + 2.3 [height (inches) - 60]
   Females = 45.5 + 2.3 [height (inches) -60]
2. Select Assist Control Mode
3. Set initial TV to 8 ml/kg PBW
4. Reduce TV by 1 ml/kg at intervals ≤ 2 hours until TV = 6ml/kg PBW.
5. Set initial rate to approximate baseline VE (not > 35 bpm).
6. Adjust TV and RR to achieve pH and plateau pressure goals below.
7. Set inspiratory flow rate above patient demand (usually > 80L/min)

OXYGENATION GOAL: PaO_2 55-80 mmHg or SpO_2 88-95%
Use incremental FiO_2/PEEP combinations below to achieve goal. Higher PEEP options (lower row) will decrease FiO_2 and may be preferred in patients with high FiO_2 who can tolerate higher PEEP (stable blood pressure, no barotrauma). Survival is similar with both PEEP approaches.

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

FiO_2	0.7	0.8	0.9	0.9	0.9	1.0	1.0	1.0
PEEP	14 20	14 20-22	14 22	16 22	18 22	20 22	22 22	24 24

PLATEAU PRESSURE GOAL: ≤ 30 cm H_2O
Check Pplat (0.5 second inspiratory pause), SpO_2, Total RR, TV and pH (if available) at least q 4h and after each change in PEEP or TV.

If Pplat > 30 cm H_2O: decrease TV by 1 ml/kg steps (minimum = 4 ml/kg).
If Pplat < 25 cm H_2O: TV < 6 ml/kg, increase TV by 1 ml/kg until Pplat > 25 cm H_2O or TV = 6 ml/kg.
If Pplat < 30 and breath stacking occurs: may increase TV in 1 ml/kg increments (maximum = 8 ml/kg).

pH GOAL: 7.30-7.45
Acidosis Management: (pH < 7.30)
If pH 7.15-7.30: Increase RR until pH > 7.30 or $PaCO_2$ < 25 (Maximum RR = 35).
If RR = 35 and $PaCO_2$ < 25, may give $NaHCO_3$.
If pH < 7.15: Increase RR to 35.
If pH remains < 7.15 and $NaHCO_3$ considered or infused, TV may be increased in 1 ml/kg steps until pH > 7.15 (Pplat target may be exceeded).
Alkalosis Management: (pH > 7.45) Decrease vent rate if possible.

Prone Positioning

Reasons to Prone

- Improved oxygenation (PaO_2)
- May improve ventilation ($PaCO_2$)
- Reduced ventilator induced lung injury
- Survival benefit in ARDS

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Physiology Behind Prone Ventilation

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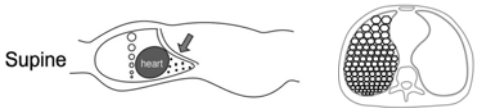

Johnson; *Resp Care* 2017.

Kallet; *Resp Care* 2014.

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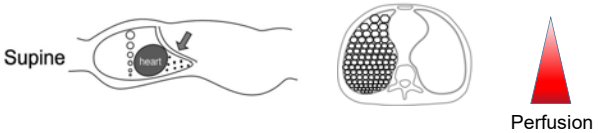

Perfusion

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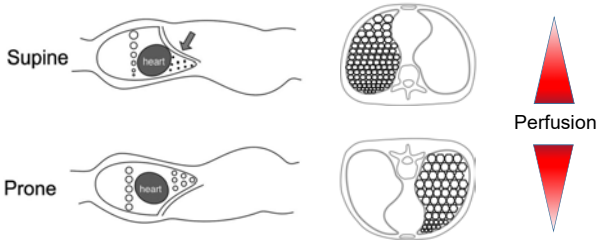

Perfusion

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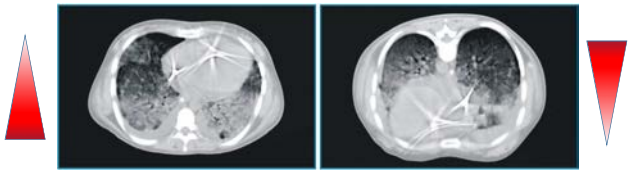
Supine / Prone



Gattinoni; *Am J Respir Crit Care Med* 2013.

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PROSEVA

- Randomized controlled trial
- 27 European hospitals
- 466 patients
- Severe ARDS
- Proned within 36 hr
- Proned > 17 hr / day


The NEW ENGLAND JOURNAL of MEDICINE

Prone Positioning in Severe Acute Respiratory Distress Syndrome

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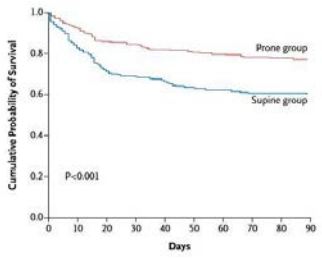
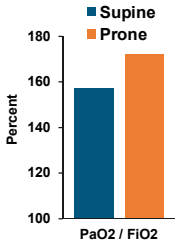
PROSEVA results





Guérin C. *N Engl J Med* 2013

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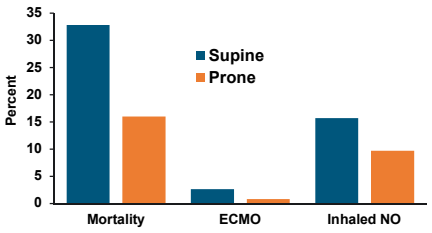
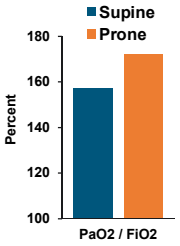
PROSEVA results





Guérin C. *N Engl J Med* 2013

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Proning Summary

- Proning beneficial in severe ARDS
- Best when used early
- Maximize prone time to achieve benefit
- Safe

VILI Summary

- #1 cause of VILI is overdistention
- $V_t \leq 6$ ml/kg IBW is protective
- Keep plateau pressures < 30

- Atelectrauma also causes VILI
- PEEP is main way to prevent it