Mechanical Ventilation of the Patient with ARDS

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1970s 1980s 1990s 2000

IMV PSV PCV Closed Loop

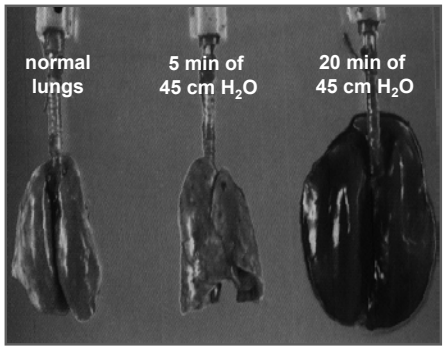
Improve ABGs Lung protection

ARDS/ALI

- Acute onset of respiratory distress
- Hypoxemia: $PaO_2/FIO_2 \leq 200$
  $PaO_2/FIO_2 \leq 300$ for ALI
- Bilateral consolidations on chest radiograph
- Absence of cardiogenic pulmonary edema

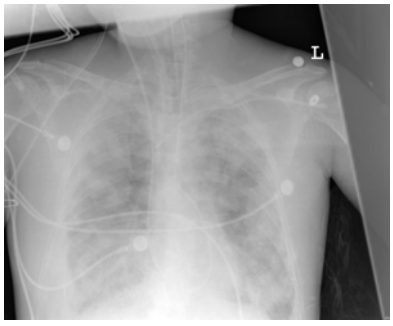
Common Causes of ARDS

- Direct lung injury (pulmonary ARDS)
  - aspiration and other chemical pneumonitis
  - infectious pneumonia
  - trauma: lung contusion, penetrating chest injury
  - near drowing
  - fat embolism
- Distant injury (nonpulmonary ARDS)
  - inflammation; sepsis syndrome
  - multiple trauma, burns
  - shock, hypoperfusion
  - acute pancreatitis



Dreyfuss, Am J Respir Crit Care Med 1998;157:294-323

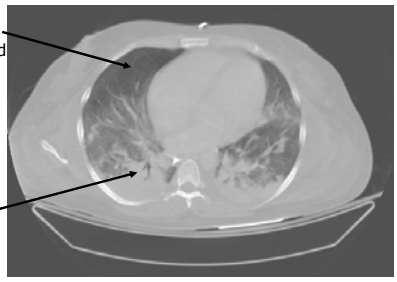
ARDS

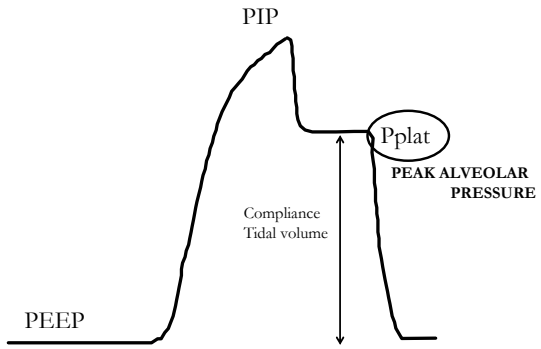


ALI/ARDS

Avoid over-distention (limit tidal volume and Plateau pressure)

Avoid derecruitment (adequate PEEP)





The New England
Journal of Medicine

VOLUME 342 MAY 4, 2000 NUMBER 18

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

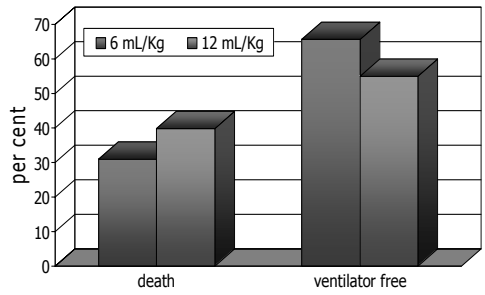
THE ACUTE RESPIRATORY DISTRESS SYNDROME NETWORK*

ARDS Network Study

- 861 patients with ALI/ARDS at 10 centers
- Patients randomized to tidal volumes of 12 mL/kg or 6 mL/kg (volume-control, assist-control, Pplat ≤ 30 cm H_2O)
- 25% reduction in mortality in patients receiving smaller tidal volume
- Number-needed-to-treat: 12 patients

N Engl J Med 2000; 342:1301-1308

ARDS Network Study



ARDS Network Study

	6 mL/kg	12 mL/kg
$PaCO_2$	43 ± 12	36 ± 9
Respiratory rate	30 ± 7	17 ± 7
PaO_2/FIO_2	160 ± 68	177 ± 81
Plateau pressure	26 ± 7	34 ± 9
PEEP	9.2 ± 3.6	8.6 ± 4.2

N Engl J Med 2000; 342:1301-1308

ARDSnet Protocol

- Calculate predicted body weight (PBW)
  - Male= 50 + 2.3 [height (inches) - 60]
  - Female= 45.5 + 2.3 [height (inches) - 60]
- Mode: volume assist-control
- Change rate to adjust minute ventilation (not >35/min); pH goal: 7.30-7.45
- Plateau pressure goal: ≤ 30 cmH_2O
- PaO_2 goal: 55-80 mm Hg or SpO_2 88-95%; use FiO_2/PEEP combinations to achieve oxygenation goal:

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

N Engl J Med 2000; 342:1301-1308

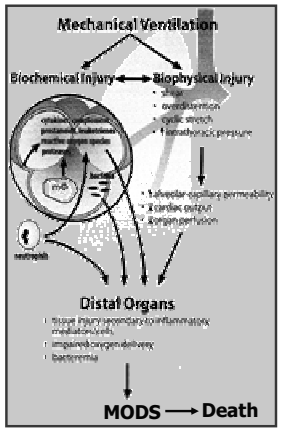
ARDSnet and Auto-PEEP

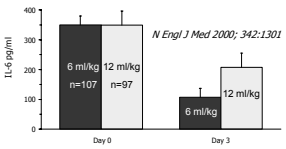
- ARDSnet did not report auto-PEEP
- Several studies have reported auto-PEEP with the respiratory rates used in ARDSnet
  - Richard et al, Intensive Care Med 2002;28:1078
  - de Durante et al, Am J Respir Crit Care Med 2002;165:1271
- When respiratory rate is increased, inspiratory time must be decreased (mean airway pressure does not change if I:E maintained constant)
- Due to lower tidal volume and increased elastic recoil (low compliance), risk of auto-PEEP is low
- Prudent to monitor auto-PEEP when ARDSnet strategy is used

ARDSnet and Long-Term Outcomes

- 120 patients randomized to low V_T or high V_T
  - 25% mortality with low tidal volume
  - 45% mortality with high tidal volume
- ≈ 20% of patients had restrictive defect and ≈ 20% had obstructive defect 1 yr after recovery
- About 80% had D_LCO reduction 1 yr after recovery
- Standardized tested showed health-related quality of life lower than normal
- No difference in long-term outcomes between tidal volume groups

Orme, Am J Respir Crit Care Med 2003;167:690





Slutsky and Tremblay
Am J Respir Crit Care Med
1998; 157: 1721-1725

Permissive Hypercapnia

- Low V_T (6 mL/kg) to prevent over-distention
  - Increase respiratory rate to avoid hypercapnia
  - PaCO2 allowed to rise
- Usually well tolerated???
- May be beneficial – "therapeutic hypercapnia"???
  Laffey & Kavanagh, Lancet 1999; 9186:1283
- Potential problems: tissue acidosis, autonomic effects, CNS effects, circulatory effects

JAMA 1994;272:957-982
AJRCCM 1994;150:870-874
AJRCCM 1994;150:1722-1737

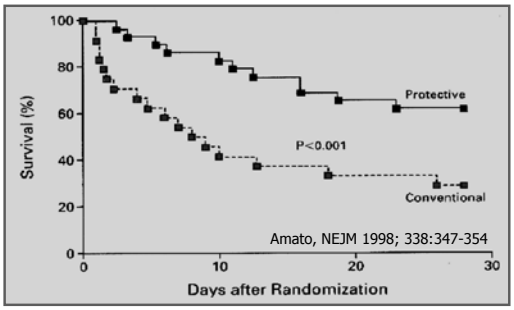
What About Non-ARDS?

- COPD: issue is air-trapping and auto-PEEP
- Patients with normal lung function; overdose, post-operative???

Open Lung Approach & Low Distending Pressure for ARDS

- Conventional approach: V_T 12 mL/kg, volume control, $PaCO_2$ 25 - 38 mm Hg, PEEP as necessary to keep $FIO_2 < 0.60$
- New approach: $V_T < 6$ mL/kg, pressure ventilation, PIP < 40 cm H_2O, permissive hypercapnia, high PEEP, recruitment maneuver

Amato, AJRCCM 1995;152:1835-1846
Amato, NEJM 1998; 338:347-354

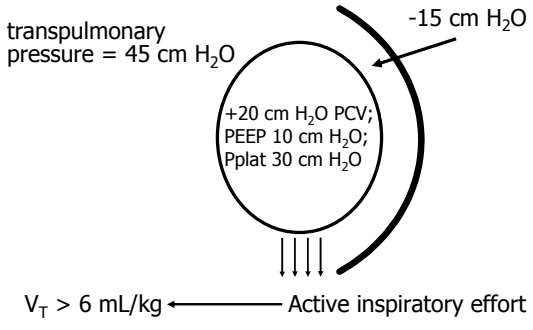


But:
Multiple interventions
Single center
High mortality in control group
Small sample size

Pressure-Controlled Ventilation

- Greatest lung strain with PC-IRV (I:E 2:1), least with PC (I:E 1:2); VC (I:E 1:2 intermediate)
  Edibam et al, Am J Respir Crit Care Med 2003;167:702
  - No difference in gas exchange, hemodynamics, and plateau pressure
  - Did not evaluate VC with descending ramp
  - Mean tidal volume 0.6 L (≈10 mL/kg? – not reported)
  - Differences between groups were small and clinical importance unknown
- No difference in outcome with ARDS patients randomized to PC (n=37) or VC (n=42)
  Esteban et al, Chest 2000;117:1690-1696

Why not PSV or PCV?



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- Number-needed-to-treat: 12 patients with ALI/ARDS

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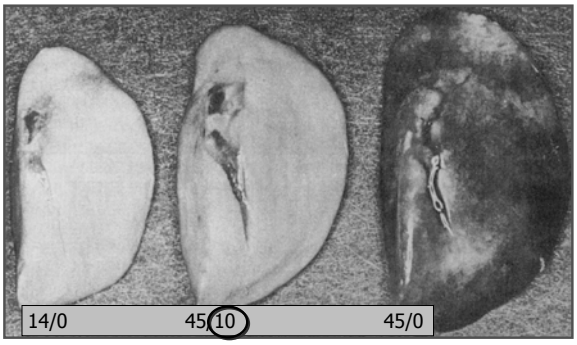

Webb and Tierney, Am Rev Respir Dis 1974; 110:556-565

How to Select PEEP?

- PEEP/FIO_2 relationship to maintain adequate PaO_2/SpO_2 (ARDSnet)

PaO_2 goal: 55 - 80 mm Hg or SpO_2 88 - 95%; use FIO_2/PEEP combinations to achieve oxygenation goal:

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

- Maintain maximal lung recruitment (open lung approach): highest PaO_2 for lowest FIO_2

Open Lung Approach & Low Distending Pressure for ARDS

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Amato, AJRCCM 1995;152:1835-1846
Amato, NEJM 1998; 338:347-354

ALVEOLI

(*A*ssessment of *L*ow tidal *V*olume and elevated *E*nd-expiratory volume to *O*bviate *L*ung *I*njury)

- Compared two PEEP levels
- PEEP separation ≈6 cm H_2O (9 ± 3.5 vs. 14.6 ± 3.6 cm H_2O)
- Stopped early at 550 patients for futility
- No safety concerns

FIO_2	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.6	0.7	0.8	0.9	1.0
PEEP	5	8	10	12	14	14	16	16	18	20	20	20	20	20	20-24

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PEEP	5	5	8	8	10	10	10	12	14	14	14	16	18	20-24

Best PEEP

- The "best PEEP" for recruitment may not be the "best PEEP" for the patient
  - "Best PEEP" for recruitment may not be "Best PEEP" to avoid over-distention
  - "Best PEEP" for the lungs may not be the "Best PEEP" for the patient
    - Hemodynamic effects
    - Renal perfusion effects
    - Cerebral perfusion effects

When all else fails ….

- Recruitment maneuvers
- Prone
- Inhaled nitric oxide
- High frequency oscillation

Unproven therapies; may improve gas exchange but effect on mortality unknown

Physiologic Benefits (PaO_2) vs Patient-Important Outcomes (Survival)

- For ARDS, inhaled nitric oxide improves PaO_2, but not mortality
  (Taylor et al, JAMA 2004;291:1603)
- High tidal volumes in patients with ARDS improves PaO_2, but mortality is lower for small tidal volumes
  (ARDSnet, N Engl J Med 2000; 342:1301)
- For ARDS, prone position improves PaO_2, but not mortality
  (Gattinoni, N Engl J Med 2001;345:568)

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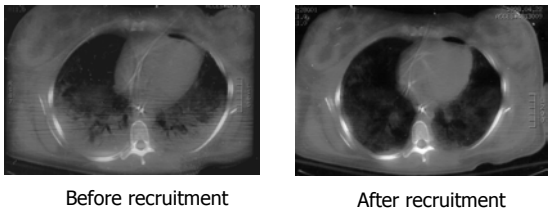
Amato, AJRCCM 1995;152:1835-1846
Amato, NEJM 1998; 338:347-354

Recruitment Maneuver: Definition

Sustained increase in airway pressure with the goal to open collapsed lung tissue, after which PEEP is applied sufficient to keep the lungs open

CPAP 40 cm H_2O for 40 seconds



Before recruitment

After recruitment

Medoff et al, Crit Care Med 2000; 28:1210

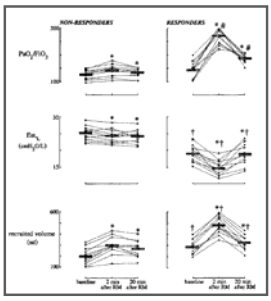
ARDSnet Recruitment

- Multi-center crossover physiologic study of recruitment maneuver versus sham
- Recruitment maneuver: CPAP 35 to 45 cm H_2O for 30 s
- Changes is SpO_2 and FIO_2/PEEP step change recorded
- Response to recruitment maneuvers highly variable
- No significant difference in oxygenation for recruitment maneuvers and sham

Step Change	After RM	After Sham
Improved	25	17
Unchanged	41	49
Worse	7	9

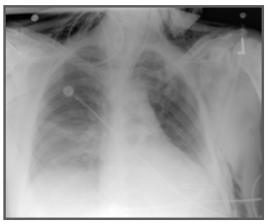
Crit Care Med 2003; 31:2592-2597

Recruitment Maneuvers in ARDS

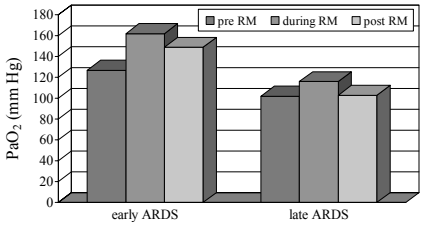


Grasso, Anesthesiology 2002; 96:795

Are Recruitment Maneuvers Safe?



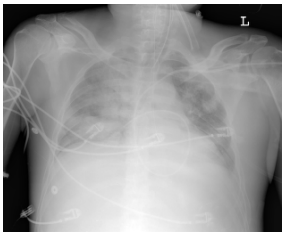
Recruitment Maneuvers



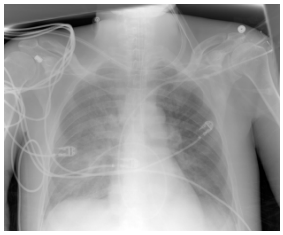
Conclusion: "…recruitment maneuvers have no short-term benefit on oxygenation, and regional alveolar over-distention … may occur"

Villagra et al, Am J Respir Crit Care Med 2002; 165:165

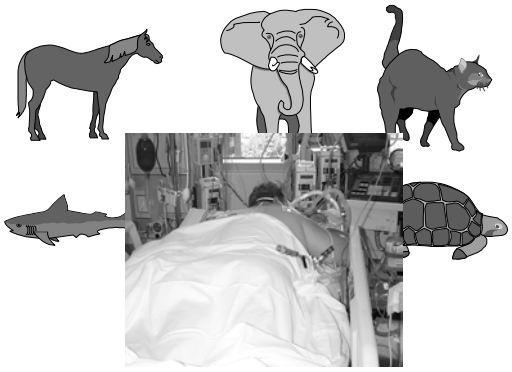
A Recruitment Maneuver?

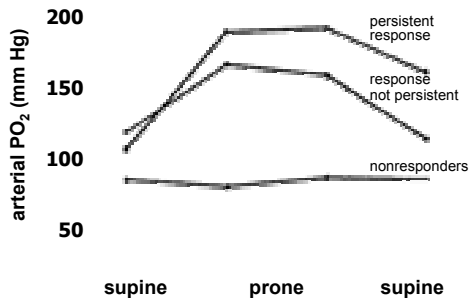


Severe abdominal distention



After 6 L abdominal fluid tap





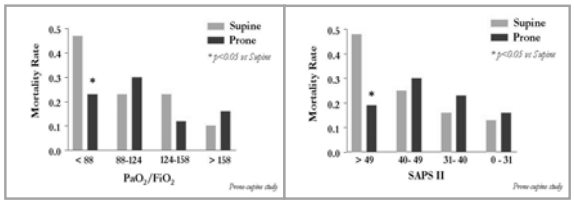
Chatte et al, AJRCCM 1997;155:473-478

Prone and Patient Outcome

- 304 patients randomized to prone versus supine
- Minimum 6 hrs per day in prone position
- No difference in complications for prone versus supine
- No overall mortality benefit for prone, but post-hoc analysis suggested potential benefit for the sickest patients

Gattinoni et al, N Engl J Med 2001;345:568

Post-Hoc Analysis



Courtesy of Dr. Luciano Gattinoni

N Engl J Med 2001; 345:568

NO: ARDS Applications

- Phase 2 study: With 5 ppm inhaled NO, increased number of days alive and off ventilator at day 28 (post-hoc)
  (Dellinger et al, Crit Care Med 1998;26:15)
- Phase 3 American trial: inhaled NO did not lead to a sustained improvement in PaO2 and did not affect outcome
  (Taylor et al, JAMA 2004;291:1603)
- Phase 3 European trial: inhaled NO did not improve survival
  (Lundin et al, Intensive Care Med 1999;25:911)
- NO did not lead to a sustained improvement in PaO2
  (Michael et al, Am J Respir Crit Care Med 1998; 157:1380)
- NO improved gas exchange, but did not improve mortality
  (Troncy et al, Am J Respir Crit Care Med 1998; 157:1483)

Airway Pressure-Release Ventilation (APRV)

- Produces alveolar ventilation as an adjunct to CPAP
- Allows spontaneous breathing at any time during the ventilator cycle
- Minimizes hazards of high airway pressure??
- Decreased need for sedation??
- Improved ventilation of dependant lung zones?

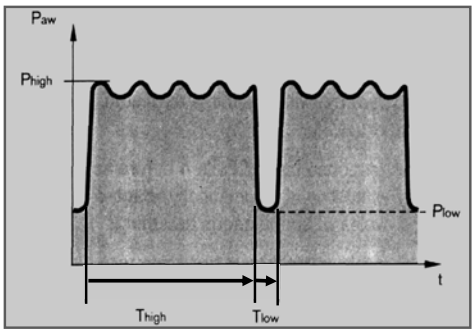
Sydow et al, AJRCCM 1994;149:1550
Putensen et al, AJRCCM 1999;159:1241
Putensen et al, AJRCCM 2001;164:43

Spontaneous Breathing

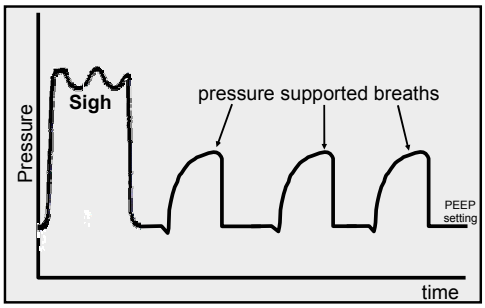
- During spontaneous breathing, the dependent part of the diaphragm has the greatest displacement
- Paralysis causes a cephalad shift of the end-expiratory position of the diaphragm (predominantly in the dependant region) and reverses the pattern of diaphragmatic displacement

Froese, Anesthesiology 1974;41:242

Airway Pressure Release Ventilation (APRV)



PCV+ (BIPAP); Bilevel

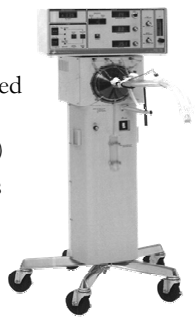


High Frequency Oscillation

- High PEEP, avoid over-distention, clear CO_2
- Case series in adults have reported efficacy (improved oxygenation and ventilation with lower FIO_2)
- Technique appears safe in adults

Forte et al, Crit Care Med 1997; 25:937
Mehta et al, Crit Care Med 2001; 29:1360

Derdak et al, AJRCCM 2002; 166:801



Are New Ventilator Modes Useful in ARDS?

The Evidence ….

Use Ventilation Strategies That

Are Effective And

Do No Harm