ARDS & MECHANICAL VENTILATION

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MAYO CLINIC, ROCHESTER MN
Mechanical Ventilation

- Noninvasive (via mask interface)
  - Simple, improved comfort
  - Decreased risk of complications (VAP, sedation)
  - Rarely used in combat trauma
    - Contraindications: inability to protect airway, shock, facial trauma

- Invasive (ETT or tracheostomy)
  - Secure airway
  - Allows full control of tidal volume, rate, respiratory effort
  - Minimizes O2 consumption (sedation, paralysis)
  - Complications
    - Ventilator Induced Lung Injury (VILI)
    - Ventilator Associated Pneumonia (VAP)
    - Barotrauma
    - Diaphragm dysfunction
    - Complications of sedation (hypotension, delirium, immobility, weakness)

Indications for Mechanical Ventilation

- Airway protection
  - Airway obstruction
  - Coma
- Shock
  - Oxygen consumption
- Respiratory failure
  - Hypercapnic
  - Hypoxemic
    - **ARDS**
ARDS: Acute Respiratory Distress Syndrome

- Acute disruption of alveolar capillary membrane
  - Pulmonary edema (not explained by heart failure)
  - PaO2/FiO2 <300 (SpO2/FiO2 <315)
  - Pathology: diffuse alveolar damage (DAD)

- Devastating complication of:
  - Injury
  - Infection
  - Surgery
  - Cancer therapy

- High mortality

- Prolonged recovery with life-long burdens

Goss et al 2003, Ware et al 2000, Rubenfeld 2005, Rice 2010
How does membrane get injured?

- **Chemical**
  - Contusion, stretch, collapse
  - Aspiration, smoke inhalation
  - Direct – Pneumonia
  - Indirect – Sepsis, transfusion, fat emboli

- **Mechanical**
  - Capillary stress

- **Biological**
  - ↑Surface Tension
  - ↑Inflammation
ARD: Predisposing Conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Percentage</th>
<th>Count</th>
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<td>Shock</td>
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<td>Aspiration</td>
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<td>Lung contusion</td>
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<td>Acute abdomen</td>
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<td>Traumatic brain injury</td>
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<td>Multiple fractures</td>
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<td>Sepsis</td>
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<td>Thoracic surgery</td>
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<td>Spine surgery</td>
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<td></td>
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<tr>
<td>Pancreatitis</td>
<td>9/325</td>
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</tbody>
</table>

ARDS in Combat Casualties

- Inhalation injury
- Lung contusion including blast injury
- Fat embolism
- Sepsis
- Aspiration
- TBI/neurogenic pulmonary edema
- Shock lung, fluid, transfusion

Park et al, J Trauma Acute Care Surg. 2016;81: S150–S156
ARDS in US combat casualties

- Of 18,329 US Department of Defense Trauma Registry encounters, 4,679 (25%) required mechanical ventilation.
- ARDS was identified in 156 encounters (3.3%).
- ARDS was independently associated with:
  - Female sex
  - Higher military-specific Injury Severity Score (Mil ISS ≥25)
  - Shock SBP <90, HR >90
  - Explosion (blast) injury was NOT associated with ARDS
- ARDS had higher mortality
  - 13% vs. 6%
ARDS in Severe Acute Brain Injury

Brain-Lung Crosstalk: Management of Concomitant Severe Acute Brain Injury and Acute Respiratory Distress Syndrome. Curr Treat Options Neurol (2022)
Key Problem: Ventilator Induced Lung Injury (VILI)

Alveolar-capillary membrane:
- Surface: ~ 1000 ft$^2$
- Thickness: ~ 0.2 microns
- Tensile strength: ~ 35 cm H$_2$O

Determinants of VILI

- Stress/Strain at the Alveolar-Capillary Membrane
  - **Duration of exposure**
    - Minutes in small animals
    - <24h if large animals, humans?
  - **Intensity of exposure (“mechanical power”)**
    - Absolute size of the breath
      - Tidal volume
      - End-inspiratory lung volume
    - Relative size of the breath
      - Size of the available lung (“baby lung”)
        - Heterogeneity (Atelectasis/Consolidation/Edema)
        - Plateau Pressure – PEEP (“driving pressure”)
  - Respiratory rate
  - Patient-ventilatory synchrony
  - Vascular pressures
- **First “Hit”**
  - Sepsis/Fluid/Transfusion
Principles of lung protective ventilation: avoiding atelectasis (atelectotrauma) and overdistension (volutrauma, barotrauma)
Principles of lung protective ventilation: avoiding atelectasis and overdistension

- **Atelectasis**
  - Shunt
  - Shear stress

- **Overdistension**
  - Stretch injury
  - Increased dead space

Stress distribution in the lung

Hubmayr RD. Am J Respir Crit Care Med. 2002 Jun 15;16

“Volutrauma”

- High tidal volume causes VILI regardless of airway pressure that can be misleading:
  - Falsely low: high spontaneous breathing effort (spontaneous breathing induced lung injury: “SILI”)
  - Falsely high: stiff chest wall (i.e. abdominal distension etc)
- It is transmural pressure that matters
Preventing Volutrauma: Low Tidal Volumes

Brower et al NEJM 1999
Preventing Atelectotrauma: Recruitment by PEEP

- **PEEP**
  - On a deflation limb of pressure volume curve
  - Taking into consideration transpulmonary pressure, body position and hemodynamics

Anes Analg. 2006 Jan;102(1):298-305
Am J Respir Crit Care Med. 2002 Jun 15;16
Intensive Care Med (2016) 42:908–911
Recruitment by position change: Prone position

- Improves ventilation perfusion matching and oxygenation
- Reduces ventilator induced lung injury

Guerine et al NEJM 2013
Recruitment by position change: Reverse Trendelenburg

Effects of Sitting Position and Applied Positive End-Expiratory Pressure on Respiratory Mechanics of Critically Ill Obese Patients Receiving Mechanical Ventilation*

Lemyze, Malcolm MD¹; Mallat, Jihad MD¹; Duhamel, Alain PhD²; Pepy, Florent MD¹; Gasan, Gaëlle MD¹; Barrailler, Stéphanie MD¹; Vangrunderbeeck, Nicolas MD¹; Tronchon, Laurent MD¹; Thevenin, Didier MD¹
Conservative fluid management to prevent fluid overload
Spontaneous Awakening and Breathing Trials

Girard et al Lancet 2008
ABCDEF, Ventilator Bundles

- A - Assess prevent and manage pain
- B - Both spontaneous awakening and breathing trials
- C - Choice of analgesia and sedation
- D - Delirium prevention and treatment
- E - Early mobility and Exercise
- F - Family engagement

- Head of bed elevation (30-45 degrees)
- Peptic ulcer, deep venous thrombosis prophylaxis

Girard et al Lancet 2008
Schweickert et al Lancet 2009
https://www.ihi.org/resources/Pages/Tools/VentilatorBundleChecklist.aspx
Challenges to lung protective ventilation

- Calculation of predicted body weight
  - Based on height and sex
- Measurement and recording of plateau pressure
- Different ventilator “modes”
- Patient tolerance of low tidal volumes, synchrony
  - Sedation, neuromuscular blockade
- Resources and training
  - Ventilator management
  - Prone position
## Table 2. Unadjusted and multivariable-adjusted predictors of not receiving LPV

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unadjusted OR (95% CI), P</th>
<th>Adjusted OR (95% CI), P</th>
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<tbody>
<tr>
<td>Age, per SD (16 y)</td>
<td>1.14 (1.02-1.28), .024</td>
<td>1.18 (1.02-1.38), .028</td>
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<tr>
<td>Race, white vs nonwhite</td>
<td>1.26 (0.99-1.60), .059</td>
<td>1.40 (1.05-1.88), .023</td>
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<tr>
<td>BMI per SD (7.3 kg/m²)</td>
<td>1.12 (0.99-1.26), .076</td>
<td>NS</td>
</tr>
<tr>
<td>Height, per SD (10 cm)</td>
<td>0.56 (0.50-0.64), .0001</td>
<td>0.55 (0.48-0.63), .0001</td>
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<tr>
<td>Weight, per SD (22 kg)</td>
<td>0.86 (0.77-0.97), .01</td>
<td>NS</td>
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<tr>
<td>SAPS II, per SD (14)</td>
<td>0.86 (0.77-0.97), .01</td>
<td>0.78 (0.67-0.92), .003</td>
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<tr>
<td>Direct lung injury</td>
<td>0.76 (0.59-0.98), .035</td>
<td>NS</td>
</tr>
<tr>
<td>Dialysis</td>
<td>3.80 (0.87-16.5), .075</td>
<td>NS</td>
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<tr>
<td>AIDS</td>
<td>0.64 (0.42-0.97), .036</td>
<td>NS</td>
</tr>
<tr>
<td>Radiographic lung injury score per SD (0.57)</td>
<td>0.84 (0.74-0.95), .005</td>
<td>0.83 (0.70-0.95), .009</td>
</tr>
<tr>
<td>Non-volume-control ventilator mode</td>
<td>3.18 (2.03-3.97), .0001</td>
<td>3.07 (1.78, 5.27), .0001</td>
</tr>
<tr>
<td>Serum bicarbonate per SD (5.5 mmol/L)</td>
<td>0.92 (0.82-1.03), .14</td>
<td>0.83 (0.71-0.97), .017</td>
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<tr>
<td>Duration of ICU stay before study enrollment per SD (2 d)</td>
<td>0.90 (0.80-1.01), .078</td>
<td>0.84 (0.73-0.98), .02</td>
</tr>
</tbody>
</table>
What Is the Evidence Base for the Newer Ventilation Modes?

Richard D Branson MSc RRT FAARC and Jay A Johannigman MD Col USAFR

The Question

The question “What is the evidence base for the newer ventilation modes?” is broad and difficult to answer. We could ask, “What is the evidence that the newer modes improve outcomes?” but that would bring this article to an abrupt end, because the answer is, “There is none.” We could in-
Volume Controlled (AC) Ventilation Mode is a Standard of Care

“I use assist control ventilation exclusively in my ICU. When the patient is stable I have the respiratory therapists use my index and do a spontaneous breathing trial. When they pass, we extubate. The rest is all unnecessary.”

Martin Tobin, MD
The problem: How to set the tidal volume?

- Height and sex are known to be better predictors of lung size than is actual body weight.

Holets SR, Hubmayr RD. How to set the ventilator 2006
<table>
<thead>
<tr>
<th>Чоловіки</th>
<th>Жінки</th>
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</thead>
<tbody>
<tr>
<td><strong>Height (inches)</strong></td>
<td><strong>Зріст (cm)</strong></td>
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<td><strong>6 ml</strong></td>
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<td>48</td>
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<td>49</td>
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<td>70</td>
<td>175.0</td>
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</table>
Default initial tidal volumes 450 for man and 350 for woman assures low tidal volume ventilation in >80% of patients.
Challenges to optimal PEEP setting

- Balance between recruitment and overdistension
- Hemodynamics effects of high PEEP/recruitment maneuvers
  - Decreased preload
  - Increased right ventricular afterload
- Misleading plateau pressure
  - Chest wall compliance
  - Spontaneous breathing effort
  - It is a transmural pressure that matters
- PEEP may increase the risk of air embolism, barotrauma (in blast injury) or intracranial pressure (in brain injury)
Setting the PEEP on decelerating part of pressure volume curve (after a “sigh”)
Recruitment maneuver (sigh): short <40 seconds at vital capacity minimizes harm

How not to do lung recruitment

- Prolonged (i.e. 2 minutes) recruitment maneuvers, HFO recruitment – the benefit is offset by hemodynamic effects of increased intrathoracic pressure

Hazard ratio, 1.20 (95% CI, 1.01-1.42); P = .041
After a sigh PEEP is set to keep Plateau Pressure < 30 (and “Stress Index” ~1) / “Driving Pressure” < 15)

Challenges with prone position

- Skilled staff for safe procedure
- Prevention of pressure ulcers
- Contraindications:
  - Hemodynamic instability
  - Facial trauma
  - Open abdomen
  - Intra-abdominal hypertension

Prone Position Demo
Patient-ventilator synchrony

- Adjust inspiratory flow and flow pattern
  - Increase in inspiratory flow
    - To match patient flow demand
    - Decrease inspiratory time and auto peep
  - Decrease inspiratory flow
    - Minimize stretch receptor stimulation
      - Particularly when patients RR is very high
  - Use decelerating flow pattern
- Increase in respiratory rate
  - Correct hypercapnia
  - Match intrinsic rate of the patient
- Sedation
  - Generally ineffective, need to balance risk/benefit
  - Opioids
- Neuromuscular blockade
  - Intermittent rather than continuous
Neuromuscular blockade

- **Bolus neuromuscular blockade for:**
  - Ventilator dyssynchrony
  - Decreased O2 consumption (for shock/refractory hypoxemia)

Challenges to restrictive fluid balance

- Accurate measurement and recording of fluid intake, output, weight
- Diuretic dosing and electrolyte replacement
- Fluid in medication infusions, “maintenance” fluid etc
Choice of Sedation and Analgesia

- Propofol (short acting, no analgesia)
  - Impairs hemodynamics

- Opioids
  - Decrease respiratory drive
  - Accumulate over time
  - Ileus/constipation
  - Withdrawal

- Benzodiazepines (no analgesia)
  - Amnesia
  - Prolonged half life, better as intermittent bolus doses
  - Withdrawal

- Ketamine
  - Analgesia
  - Short acting
  - Hallucinations, consider adjunct benzodiazepine

- Dexmedetomidine
  - Analgesia
  - Bradycardia and hypotension
  - Withdrawal
Sedation and Analgesia During Transport

**TIVA: total intravenous anesthesia in a stick**

- TIVA stick (5 mL)
  - Ketamine 50mg/1mL (3 mL – 150 mg)
  - Midazolam 5mg/mL (1 mL – 5 mg)
  - Fentanyl 50mcg/mL (1 mL – 50 mcg)
- Give 2 mL for sedation (titrate no nystagmus)
  - Add 1 mL as needed
  - Double the doses if IM instead of IV
- For RSI give entire stick (5 mL)
- Consider ondansetron (4mg IV/IM to prevent vomiting)
- Vecuronium 10-20mg bolus for neuromuscular blockade

https://prolongedfieldcare.org/2017/12/21
Challenges to spontaneous awakening and breathing trials

- Different pharmacokinetic and pharmacodynamic properties of sedative agents
- Coordination between nurses, respiratory therapists, pharmacists and physicians
  - Working in shifts
- Concerns for spontaneous breathing induced lung injury (large spontaneous tidal volumes)
Failure to wean

- CNS
  - Encephalopathy or delirium
  - Anxiety
  - TBI
  - Sedatives/narcotics

- Cardiopulmonary
  - Baseline heart/lung disease
  - Pulmonary edema/fluid overload
  - Airway edema/obstruction
  - Weak cough/Secretions

- Nerve/muscle
  - Critical illness neuropathy/myopathy

- Metabolic
  - Low PO4, K, Mg
Challenges with hypoxemia and hypercapnia

- Permissive hypercapnia not harmful unless hemodynamic consequence
  - pH>7.15 usually well tolerated
  - Contraindications
    - Increased ICP
    - Severe right ventricular failure
- Permissive hypoxemia?
  - Balance the risks of low PaO2, high FiO2 and the interventions
- Interaction between shock (low venous O2 saturation) and shunt
Identify shock before alveolar recruitment

Aim to

- Reduce oxygen consumption
- NMB
- Increase O2 delivery

Standardized approach to severe hypoxemia

- **Step 1 baseline:** ABC + Neuromuscular blockade + FIO2 to 100%
  - Basic assessment and stabilization (airway assessment, ventilator circuit, breath sounds, pulse, minimize oxygen consumption)

- **Step 2 assessment:** CXR+ECHO+VBG+RM
  - Shock (low SvO2) vs shunt vs both?
  - Recruitability: Response to recruitment/decremental PEEP trial
  - RV dysfunction/pulmonary hypertension/PE?
  - Lobar atelectasis?
  - LV dysfunction/intracardiac shunt

- **Step 3 customized management:**
  - Shock treatment based on type of shock
  - Higher PEEP (after recruitment) for recruitable lungs
  - Prone position for poorly-recruitable lungs after recruitment
  - Bronchoscopy for lobar atelectasis
  - Inhaled vasodilators for pulmonary hypertension
  - ECMO for refractory cardiopulmonary dysfunction
## Evidence Based Management

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Definition</th>
</tr>
</thead>
</table>
| Mechanical ventilation            | 1) Time limited trial of noninvasive support  
2) Limit tidal volumes, pressure swings & FiO2  
3) Maximize patient-ventilator synchrony  
4) Recruit flooded/collapsed lung (body position/PEEP)  
5) Prevent dynamic hyperinflation and barotrauma  
6) Prevent VAP                                                                                   |
| Spontaneous awakening & breathing trials | Choice of sedative agents, daily spontaneous breathing trials, physical therapy, family support (ABCDEF bundle)                                      |
| Hemodynamic support               | Maintain organ perfusion pressure, match oxygen delivery and consumption, prevent/treat cardiac arrhythmia                                         |
| Restrictive fluid balance         | Limit IV fluid, use diuretics/dialysis, maintain electrolytes                                                                               |
| Anti-inflammatory treatment       | Antimicrobials, steroids                                                                                                                  |
| Other supportive measures         | Nutrition, stress ulcer prophylaxis, minimize device use and complications                                                                |
#### CERTAIN Checklist

<table>
<thead>
<tr>
<th>Rounding checklist: System based plan of care</th>
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<td>□ Контроль ПХО ран</td>
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