Disease Specific Management Strategies for Mechanically Ventilated Infants

Robert DiBlasi RRT-NPS, FAARC
Pathophysiology of RDS

Atmospheric Pressure

nCPAP 6 cmH₂O

Courtesy of Siew, M Monash Univ, Australia
Not all infants can be supported with N-CPAP alone……

25-50% of infants fail nCPAP as initial form of support (Morley, 2008)

25-38% of infants fail nCPAP following extubation (Stefanescu, 2003)

Predictors for infants failing CPAP include lower birth weight \(\leq 750 \text{ g}\) and gestational age \(\leq 26 \text{ wk}\) (Ammari, 2005)
Perhaps the only consensus about mechanical ventilation of infants is that, all else being equal, avoidance of mechanical ventilation is the best way to avoid lung injury.

Don’t worry—I did this on a sedated cat once!
ET tube induced complications

- Traumatic and painful
- Hemodynamic instability
- Infection - Sepsis
- ↑ Airway emergencies
- ↑ Resistance/WOB
- ↑ Incidence of air-leak
- Permanent airway lesions
- Machine-triggered IMV/ no PEEP
  Initial description of N-CPAP
- Neonatal NIV
- Patient-triggered IMV/PEEP
- Surfactant Replacement
- Widespread Use of Maternal Corticosteroids for Fetal Lung Maturation
- Nitric Oxide/ HFOV
- N-CPAP/ NIV

Singh GK, J Pub Health, 1995
What are the recent technologic improvements with ventilators?

- Cradle to grave
- Proximal Flow sensors
  - Patient-triggered ventilation
  - Airway graphics
  - Tidal volume monitoring
- Active PEEP/exhalation valves
- Volume-targeted (modes)
- Pressure support
- Flow cycled ventilation

Have improvements in neonatal ventilator technology actually improved outcomes in children?
Patient-triggered ventilation was associated with a shorter duration of ventilation in patients than machine-triggered modes ($p=0.0134$; Greenough et al.)
Is there a standard approach or device for infant mechanical ventilation?

“We have adopted changes in our practice more on the types of technology available than on data generated from large, randomized controlled trials”

-Mark Mammal
Therapist Driven Protocols

FIGURE 2
Extubation failure. \( a \) \( P < .05 \).

FIGURE 3
Length of MV. \( a \) \( P < .05 \).

Hermeto, Pediatrics, 2009
"The tedious argument about the virtues of respirators not invented over those readily available can be ended now that it is abundantly clear that the success of such apparatus depends on the skill with which it is used"

-Lancet 2:1227, 1965
Approaches to Infant Ventilation

LOVE- Laws of Ventilator Efficiency

1. Know thy ventilator and disease pathology
2. Develop a specific strategy for the pathophysiology in each individual patient
3. Change the ventilatory strategy as the pathophysiology changes
4. Always strive to wean the patient off of ventilatory assistance
“When in doubt, let the kid make his own dawn ventilator changes”

- Courtney
Monitoring During Mechanical Ventilation
Neurological Complications of Mechanical Ventilation
Respiratory Distress Syndrome (RDS)
Ventilation Strategy for RDS

**Settings**

1. Rapid Respiratory Rates
   - ≥ 60 breaths/min
2. PIP 10-15 cmH\(_2\)O
   - target \(V_T\) 4-6 mL/kg
   - Institute HFOV for PIP>25
   - Not ECLS candidate
3. PEEP 4-5 cmH\(_2\)O
4. Short Inspiratory Times
   - 0.25-0.4 s (GA)
5. Nitric Oxide is investigational

**Blood Gases**

1. Permissive Hypercapnea
   - \(pCO_2\) levels 45-65
   - pH 7.25-7.3
2. Less Aggressive Oxygenation Goals
   - \(paO_2\) 45-55
   - Saturations 85-92%
27 Wk Preemie; 850 grams

Compliance 0.3 mL/cm H2O
SIMV/PC  FiO2 0.80  RR 60  PIP 26  PEEP 6 Ti 0.3 sec
Tidal Volume: 6 mL/kg
ABG:  7.20 / 65 / 65 / 14
Case Progression
12 hrs post-surfactant

Compliance 1 mL/cm H2O
SIMV/PC  FiO2 0.50  RR 50  PIP 24  PEEP 6 Ti 0.3 sec
Tidal Volume: 20 mL/kg
ABG: 7.49 / 25 / 65 / 18
How many and how much is enough?

- Even Short-term ventilation with excessive $V_T$ and insufficient PEEP can initiate injury in the preterm lung and ignite a systemic inflammatory response (Hillman, Pediatric Research, 2007)

- As few as 6 manual inflations, using large $V_T$, compromises the therapeutic effect of subsequent surfactant replacement (Bjorklund, Pediatric Research, 1997)
Volume targeted modes for infants

- Weaning of PIP and mPaw over the first 24 hours may help to prevent lung disease (*Shaun Morris*, *Karen Choong*)

- Ventilation at low PIP and low lung volumes can also create VILI due to atelectrauma (*Muscedere J Respi Crit Care 1994*)

- Automatically adjusts the PIP level to maintain a minimum preset $V_T$ without having to be at the bedside

- PC level will adjust in response to changes in lung mechanics on a breath-to-breath basis to target a minimum inspiratory or expiratory $V_T$
Clinical Data

Cochrane: 4 RCTs, n=178 Comparing volume-targeted to pressure-limited ventilation

- volume-targeted ventilation resulted in significant reductions in:
  - duration of ventilation
  - rates of pneumothorax
  - rates of severe (Grade 3 or 4) intraventricular hemorrhage
  - Death/BPD

H₀: There are no differences in the neonatal ventilators’ ability to provide stable tidal volume delivery in an erratically breathing lung model of a premature neonate during Adaptive Pressure Control.
Neonatal Volume Precision-Adaptive PC Modes (large ET-tube Leak)

Tidal Volume Target (5 mL)

PB 840 Volume Support
Mean±SD: 6.50±4.95
Range: 0.24-23.74 mL, CV: 76%

GE CareStation PSVG
Mean±SD: 5.27±2.25
Range: 0.19-13.61 mL, CV: 43%

Drager VN-500 PSVG
Mean±SD: 5.04±2.17
Range: 0.20-12.39 mL, CV: 43%

AVEA Prototype
Mean±SD: 7.19±2.08
Range: 0.21-12.50 mL, CV: 29%

AVEA Machine Volume
Mean±SD: 5.43±1.64
Range: 0.38-12.0 mL, CV: 30%
What mode should be used for volume guarantee in the initial phase?

- In the acute phase of lung disease, it is suggested that the A/C mode be used, rather than SIMV, so that every breath has a $V_T$ target
- Infants supported by SIMV were more tachypneic, ↑HR, and consistently ↓SpO$_2$, suggesting ↑WOB when compared to volume-targeted/AC (Kezler et al., 2005)
- In a RCT comparing $V_T$/SIMV to $V_T$/AC
  - CMV resulted in more consistent tidal volumes at lower total respiratory rates than SIMV (Mrozek et al., 2008)
Lung Inflammation in Preterm Infants With Respiratory Distress Syndrome: Effects of Ventilation With Different Tidal Volumes

Gianluca Lista, MD,1* Francesca Castoldi, MD,1 Paola Fontana, MD,1 Roberta Reali, MD,2 Alessandro Reggiani, MD,2 Silvia Bianchi, MD,1 and Gilberto Compagnoni, MD1

Fig. 2. Levels of tracheal IL 6 on days 1, 3, and 7 of life (values expressed as medians). P = ns.

Fig. 3. Levels of tracheal TNF-α on days 1, 3, and 7 of life (values expressed as medians). *P < 0.05, VG 3.0 vs. VG 5.0 group.
## Tidal Volume Prescription

<table>
<thead>
<tr>
<th>Clinical situation</th>
<th>Tidal volume</th>
<th>Pressure limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preterm infant with RDS, &gt;2000 g</td>
<td>4 ml/kg</td>
<td>30 cm H$_2$O</td>
</tr>
<tr>
<td>Preterm infant with RDS, 700–1500 g</td>
<td>4–5 ml/kg</td>
<td>25–28 cm H$_2$O</td>
</tr>
<tr>
<td>Preterm infant with RDS, &lt;700 g</td>
<td>5–6 ml/kg$^a$</td>
<td>25 cm H$_2$O</td>
</tr>
<tr>
<td>Preterm infant with BPD</td>
<td>5–7 ml/kg$^b$</td>
<td>30 cm H$_2$O</td>
</tr>
<tr>
<td>Term infant with MAS</td>
<td>5–7 ml/kg$^b$</td>
<td>30 cm H$_2$O</td>
</tr>
<tr>
<td>Term infant with CDH</td>
<td>4 ml/kg$^c$</td>
<td>25 cm H$_2$O</td>
</tr>
<tr>
<td>Term infant with pneumonia</td>
<td>4 ml/kg</td>
<td>25–30 cm H$_2$O</td>
</tr>
</tbody>
</table>

$^a$ Smallest infants need larger tidal volume to compensate for the dead space of the flow sensor.

$^b$ Depending on the severity of the disease.

$^c$ Low threshold to change to high-frequency ventilation.
CAUTION
THIS MACHINE HAS NO BRAIN
USE YOUR OWN
Chronic Lung Disease (CLD)

- **Definition of CLD**
  - $O_2$ dependency or respiratory support at 36 weeks postmenstrual age

- **Etiology**
  - Lung and airway damage caused by:
    - Ventilation and $O_2$

*Figure Courtesy of VON*
Chronic Lung Disease
Ventilation Strategy for CLD

Settings

1. Slow Respiratory Rates
   • < 40 breaths/min
2. PIP (lowest required)
   • target $V_T$ 5-12 mL/kg
   • Not ECLS candidate
3. PSV/VG
4. PEEP
   • 5-6 (up to 12 for bad TM)
5. Short-Long Inspiratory Times
   • 0.4-0.7 s

Blood Gases

1. Permissive Hypercapnea
   • $pCO_2$ levels 45-65*
   • pH 7.25-7.35
2. Less Aggressive Oxygenation Goals
   • $paO_2$ 45-55*
   • Saturations 85-92%
Limitations of ventilation in patients with airway obstruction

Fig. 1 Representative example of airway pressure, airway flow, and esophageal pressure tracings (not actual patient data). Above Airway pressure; middle airway flow, with inspiration (Insp) in the upward direction and expiration (Exp) in the downward direction; below esophageal pressure tracing. a End-exhalation; c end inspiration; b inspiratory flow actually begins. Vertical hatch mark through point b Time when inspiratory flow begins on all panels. The esophageal pressure begins to drop at point a as the patient attempts to initiate a breath. However, flow does not begin until point b. Gray area (the difference between lines ac and bd) Pressure work that the patient must do to overcome PEEPi before any inspiratory flow can occur; smaller hatched area below the line bd pressure work actually related to inspiratory airflow; vertical line with double arrowheads total change in esophageal pressure. (Modified from MacIntyre et al. [6] with permission)

Graham and Newth, Intensive Care Medicine, 2007
PEEP and PSV in kids with BPD

Fig. 3 Pressure-rate product (PRP) changes during each tier. First tier of the protocol, with end-expiratory pressure fixed at zero (ZEEP): PRP decreases as PS increases. Second tier of the protocol, PS is fixed at 8 cmH₂O: PRP decreases by 59% as PEEPe increases. Third tier, PEEPe determined from the second tier was set on the ventilator and remained fixed: PRP was recorded at increasing levels of PS. The lowest PRP of 136 ± 128 cmH₂O/min in the entire protocol was achieved at PS 16 cmH₂O over PEEPe. All analyses by repeated measures analysis of variance. *p<0.05, **p<0.01, ***p<0.001 vs. baseline within tier.
<table>
<thead>
<tr>
<th></th>
<th>Before Heliox, Mean (SD)</th>
<th>At 10 min of Heliox, Mean (SD)</th>
<th>At 60 min of Heliox, Mean (SD)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIP, cm H₂O</td>
<td>21.4 (1.2)</td>
<td>20.0 (2.5)</td>
<td>17.5 (3.7)</td>
<td>.0008</td>
</tr>
<tr>
<td>MAP, cm H₂O</td>
<td>8.5 (0.8)</td>
<td>8.4 (1.1)</td>
<td>8.0 (1.6)</td>
<td>NS</td>
</tr>
<tr>
<td>RR, breaths per min</td>
<td>45.9 (12.3)</td>
<td>48.8 (9.7)</td>
<td>55.6 (16.0)</td>
<td>NS</td>
</tr>
<tr>
<td>Fio₂</td>
<td>0.33 (0.08)</td>
<td>0.33 (0.08)</td>
<td>0.33 (0.08)</td>
<td>NS</td>
</tr>
<tr>
<td>O₂ saturation, %</td>
<td>94.2 (2.8)</td>
<td>95.7 (2.9)</td>
<td>96.1 (2.6)</td>
<td>NS</td>
</tr>
<tr>
<td>Tcpo₂, mm Hg</td>
<td>42.8 (10.6)</td>
<td>45.5 (10.4)</td>
<td>46.7 (10.3)</td>
<td>.0024</td>
</tr>
<tr>
<td>TcpcO₂, mm Hg</td>
<td>52.3 (7.6)</td>
<td>49.7 (6.3)</td>
<td>49.1 (6.8)</td>
<td>.0024</td>
</tr>
<tr>
<td>V̇min, mL/kg per min</td>
<td>332 (62)</td>
<td>420 (115)</td>
<td>478 (149)</td>
<td>.0004</td>
</tr>
<tr>
<td>Cdyn, mL/cm H₂O per kg</td>
<td>0.48 (0.31)</td>
<td>0.63 (0.40)</td>
<td>0.63 (0.31)</td>
<td>NS</td>
</tr>
<tr>
<td>Cstat, mL/cm H₂O per kg</td>
<td>0.59 (0.30)</td>
<td>0.48 (0.23)</td>
<td>0.61 (0.29)</td>
<td>NS</td>
</tr>
<tr>
<td>WOB, joule/L</td>
<td>0.46 (0.39)</td>
<td>0.34 (0.36)</td>
<td>0.22 (0.24)</td>
<td>.0152</td>
</tr>
</tbody>
</table>
Meconium Aspiration Syndrome (MAS)

- Meconium-stained fluid (~12% of live births)
- Meconium present below the cords (1/3)
- Incidence of MAS 2 of every 1000 live-born infants
- 95% of infants with inhaled meconium clear the lungs spontaneously

http://library.med.utah.edu/WebPath/jpeg2/PLAC017.jpg
MECONIUM HAPPENS!
Ventilation Strategy for MAS

Settings

1. Relatively Rapid Respiratory Rates
   • 40-60 breaths/min

2. Lowest PIP sufficient for chest excursion
   • Start at 16/5 and institute HFOV for PIP>25
   • target $V_T$ 5-7 mL/kg BW
   • ECLS for mPaw>14
   • Heavy sedation for gas trapping

3. Short Inspiratory Times
   • 0.3-0.5 s
   • Longer Expiratory Times and lower PEEP for gas trapping

4. Nitric Oxide works well in this population

Blood Gases

1. No pulmonary hypertension
   • $pCO_2$ levels 40-50
   • $pH \geq 7.30$
   • $PaO_2$ 70-80

2. Pulmonary hypertension
   • $pCO_2$ levels 30-35
   • $pH \geq 7.35$
   • $PaO_2$ 80-100
Ventilation Strategy for MAS

Figure 4 Incremental improvement in oxygenation with different levels of positive end expiratory pressure in the treatment of meconium aspiration syndrome. From reference 20 with permission.

Fox WW, Pediatrics, 1975
Airflow Scalars in a patient with MAS

Inspiratory Time 0.5 s

Inspiratory Time 0.3 s
Congenital Diaphragmatic Hernia (CDH)
Congenital Diaphragmatic Hernia (CDH)
Ventilation Strategy for CDH

Settings

1. Rapid Respiratory Rates
   • 40-80 breaths/min

2. Lowest PIP sufficient for chest excursion
   • Start at 16/5 and institute HFOV for PIP>25
   • ECLS for mPaw>14
   • $V_T$ 4 mL/kg
   • Accept rapid shallow breathing

3. PEEP
   • 3-5

4. Short Inspiratory Times
   • 0.3-0.5 s

Blood Gases

1. Permissive Hypercapnea
   • $pCO_2$ levels 45-65
   • $pH \geq 7.24$ (7.14 first few hours)

2. Less aggressive Oxygenation Goals
   • preductal saturation $\geq 80-85\%$
<table>
<thead>
<tr>
<th></th>
<th>CDH</th>
<th>Non CDH (n = 23)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before Surgery (n = 14)</td>
<td></td>
</tr>
<tr>
<td>Tidal Volume (ml/kg)</td>
<td>4.61 ± 0.80</td>
<td></td>
</tr>
<tr>
<td></td>
<td>After Surgery (n =17)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.52 ± 0.82</td>
<td>4.87 ± 0.73</td>
</tr>
<tr>
<td>Respiratory rate (per minute)</td>
<td>58.4 ± 6.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>56.6 ± 4.6</td>
<td>54.4 ± 7.8</td>
</tr>
<tr>
<td>Minute ventilation (ml/kg/min)</td>
<td>272.2 ± 44.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>249.2 ± 47.2</td>
<td>265.3 ± 50.6</td>
</tr>
<tr>
<td>PaCO₂</td>
<td>43.7 ± 2.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>44.8 ± 2.9</td>
<td>42.4 ± 3.2</td>
</tr>
</tbody>
</table>

*Kezler M et al., PAS 2010*
# PPHN: Commonly Occurs with These Diseases

<table>
<thead>
<tr>
<th>Meconium Aspiration Syndrome</th>
<th>Respiratory Distress Syndrome</th>
<th>Idiopathic PPHN</th>
<th>Congenital Diaphragmatic Hernia</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Airway obstruction with gas trapping</td>
<td>- Acute lung injury</td>
<td>- No underlying lung disease</td>
<td>- Lung hypoplasia</td>
</tr>
<tr>
<td>- Surfactant inactivation</td>
<td>- Surfactant deficiency or inactivation</td>
<td></td>
<td>- Decreased vascular surface area</td>
</tr>
<tr>
<td>- Pneumonitis</td>
<td>- Pulmonary edema, volume loss</td>
<td></td>
<td>- Increased pulmonary artery muscularity</td>
</tr>
</tbody>
</table>

PPHN = persistent pulmonary hypertension of the newborn.

Images courtesy of John P. Kinsella, MD, and Steven H. Abman, MD.
Primary Pulmonary Hypertension Of the Newborn

Pressure in pulmonary arterial system exceeds systemic pressure
Hemodynamic Complications of Ventilated Newborns with Lung Disease
# Ventilation Strategy for PPHN

## Settings

1. **Rapid Respiratory Rates**
   - 50-70 breaths/min
2. **PIP 15-25**
   - target $V_T$ 4-6 mL/kg
   - Institute HFOV for PIP>25
   - ECLS for mPaw>14
3. **PEEP 3-4**
4. **Short Inspiratory Times**
   - 0.3-0.5 s
5. **High FiO₂**

## Blood Gases

1. **Mild Hyperventilation**
   - pCO₂ levels 30-40
   - pH 7.4-7.6
2. **Aggressive Oxygenation Goals**
   - paO₂ 70-100
Weaning from mechanical ventilation

- Weaning should be performed in small steps:
  - Wean PIP by 1-2 cmH₂O during PCV
  - Wean FiO₂ by 0.10
- Extubation from low rate ventilation is associated with a trend towards an increased chance of successful extubation and reduced apnea when compared to extubation after a period of endotracheal CPAP (Cochrane)
- When applied to preterm infants being extubated following IPPV, nasal CPAP reduces the incidence of respiratory failure indicating the need for additional ventilatory support (cochrane)
- Compared with nCPAP, NIPPV showed a significant benefit for infants extubated to NIPPV in terms of prevention of extubation failure criteria.