“Gentle” Approach to Neonatal Invasive Mechanical Ventilation

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Objective

- Challenges in Neonatal Ventilation
- Application of Lung Protective Strategies
- Touch on Volume Targeted Ventilation: Theory and Function
Challenges in ventilating neonates

- Uncuffed ETT
- High respiratory rate (RR); short inspiratory time (Ti)
- Small tidal volumes
- Dynamic changes in lung compliance
Immature germinal matrix of premature babies make them more susceptible to developing Intraventricular Hemorrhage (IVH) or Periventricular Leukomalacia (PVL)
The Journey toward Lung Protective Strategies
Integration means another race has the right to enjoy the same poor service and bad food the rest have been given all these years.

Jackie Gives Birth To Son Prematurely
Wife of President Rushed to Hospital

Kennedy Baby Dies At Boston Hospital; President at Hand
By The Associated Press
BOSTON, Friday, Aug. 9---The new baby boy of President and Mrs. Kennedy died

BABY SPED TO BOSTON
Has Trouble Breathing; Kennedy Stands by Here

‘He’s a Kennedy --He’ll Make It’
Early Infant Ventilators

Pressure regulated
Time cycle

1990s: improved microprocessors
Allow for detection of patient efforts
Still had issues compensating large leak
Infants are not small adults...
WEIRD ‘COW FOAM’ CURE MIGHT HAVE SAVED KENNEDY BABY
TRAUMA associated with mechanical ventilation

Endotrauma
**Volutrauma**
**Barotrauma**
**Alectotrauma**
Biotrauma
Oxidative trauma

**VOLUME INDUCED LUNG INJURY (V.I.L.I)**

Even short-term ventilation can result in some degree of lung injury

Neurological damage from Hyper or Hypo ventilation
Animals whose chest wall and diaphragmatic excursion were limited by external binding to minimize large swings in tidal volume experienced much less acute lung damage when exposed to the same high inspiratory pressure.
It is primary VOLUTRAUMA that injures the neonatal lung.
Brain health is very important

\[ (MV) = \text{Respiratory Rate (RR)} \times \text{Tidal Volume (VT)} \]
Effect of CO$_2$ on the Brain

**Too high CO$_2$**
- Vasodilation of vessels to the brain
- Increased blood flow
- Intraventricular hemorrhage (IVH)

**Too low CO$_2$**
- Vasoconstriction of vessels to the brain
- Decreased blood flow
- Decrease O$_2$
- Ischemia
- and/or Periventricular leukomalacia (PVL)

Rapid change/fluctuating pCO$_2$ probably most damaging

Inadvertent hyperventilation to arterial partial pressure of carbon dioxide (PaCO$_2$) less than 25 mm Hg in 30% of ventilated newborn infants during the first day of life
VOLUME TARGETED VENTILATION
VOLUME TARGETED VENTILATION

Advantages:
• Minute Ventilation = RR X VT
• More control over blood CO2
• Changes in PIP can indicate changes in compliance or resistance of the lungs
• Can set PIP limit
• Can VENTILATE WITH A LEAK
• Adjustment with each breath for Tidal volume lost to leak or circuit
Volume Targeted Ventilation

- It is **Pressure regulated** – **volume targeted**, time cycled, pressure limited
- Compares **exhaled VT** of previous inflation and adjusts PIP up or down to try to achieve the set VT
Pressure Limited Ventilation versus Volume Targeted Ventilation

- Much larger variation in tidal volume
- An example of VG mode changing the PIP to control the tidal volume
Why use exhaled VT?
Advantages

**Volume-targeted versus pressure-limited ventilation in neonates**

- Compared 16 parallel studies and 977 babies showed that VTV compared the PC resulted in a reduction of:
  - Death/BPD
  - Pneumothoraces
  - Duration of Ventilation
  - Severe Intraventricular Hemorrhages (IVH) – Grade 3 and 4
  - Hypocarbia/Periventricular Leukomalacia (PVL)

(Klingenberg C, et al Cochrane Database of Systematic Reviews 2017, Issue 10)

- Better control over CO\(_2\) using Volume Guarantee due to consistent tidal volume
  - High CO\(_2\) → vasodilates cerebral vasculatures → IVH
  - Low CO\(_2\) → vasoconstrict cerebral → PVL

  **Rapid change/ fluctuating pCO\(_2\) probably most damaging**

- Guards against volutrauma by targeting specific tidal volume range
Automatic lowering of PIP level – real time “weaning”
The Respiratory Equation of Motion

\[ \Delta \text{Pressure} = R_{AW} \times \text{Flow} + \text{Volume/Compliance} \]

- **Ventilating pressure** (pressure to deliver the tidal volume)
- **Resistive pressure** (to make air flow through the airways)
- **Elastic pressure** (to inflate the lungs and chest wall)

**Airway:** Trachea, bronchus, bronchioles

**ETT**

**Lungs**

**Chest Wall/Abdomen**

**PIP** varies based on changes in **lung compliance, airway resistance**, and **patient effort** without impacting tidal volume.
What if you don’t have Volume Target Ventilation?

1. Set PIP and adjust according to chest rise.
2. Target measured tidal volume: 4-6 ml/kg
3. USE the TRANCUTANEOUS CO2 monitor
   - CORRELATE with a gas
   - SET ALARM LIMIT appropriately!!!
PC-AC versus SIMV?

- In the acute phase of lung disease, it is suggested that Pressure Control Assist Controlled (PC AC) be used over Synchronized Intermittent Mandatory Ventilation (SIMV).

- Time constant is shorter during acute phase and a more stable Ti is needed.

AC results in more even tidal volume ($V_T$), lower work of breathing, and more rapid weaning from mechanical ventilation compared to SIMV.

Infants supported by SIMV were more tachypneic, increased WOB and consistently has SpO2 instability.
WHY USE 4-6 mL/kg?

- CO₂ clearance is dependent on minute ventilation.
  \[ \text{Alveolar minute ventilation} = (\text{VT} - \text{Vt deadspace}) \times \text{RR} \]

- Since deadspace is equal to 2-2.5 ml/kg, a VT of at least twice this is needed for adequate ventilation.

(Lista G. et al, Pediatr Pulmonol 2006 Apr;41(4):357-63)

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**Fig. 1.** Levels of tracheal IL 8 on days 1, 3, and 7 of life (values expressed as medians). *P < 0.05, VG 3.0 vs. VG 5.0 group.*
Set Inspiratory Time (Ti): 0.30-0.40 sec

- The time from the onset of inspiration to the beginning of exhalation
- Set using the flow –time graph
- Long enough for lungs to fill
Set Respiratory Rate: 30-40 breath/min

- RR set at 30/min resulted in more triggered breath than 50/min
- It is important that infants trigger as many inflations as they need ... their PIP requirement will be lower
- It also continues to allow the diaphragm to function and develop as apposed to becoming “lazy” and atrophied

<table>
<thead>
<tr>
<th>Back up rate</th>
<th>30/min</th>
<th>40/min</th>
<th>50/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delivered inflations</td>
<td>56(6)</td>
<td>58(9)</td>
<td>62(8)</td>
</tr>
<tr>
<td>% triggered</td>
<td>85 (11)%</td>
<td>75 (19)%</td>
<td>61 (25)%</td>
</tr>
</tbody>
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Wheeler, KI et al, J of Perinatology 2012
Volume needs to be distributed evenly throughout an “open lung”!!
- Set according to lung conditions, FiO2 requirement, chest xray
- Watch blood pressure closely
## Practice Points

| PaCO₂ target range 40-60mmHg (may be higher in babies with CLD) | • avoids use of excessive pressure and tidal volumes which are harmful to the lung  
• avoids low PaCO₂ which causes cerebral vasoconstriction leading to PVL in preterm babies |
|---|---|
| Target arterial pH >7.25 | • FOR INTUBATED AND VENTILATED PATIENTS  
• Kidneys are immature and can take up to one week before you see a correction with bicarb |
| Tertiary Care Centres including SickKids use target range 90-95% in ALL babies | • In extremely preterm infants, targeting lower (85% to 89%) SpO₂ compared to higher (91% to 95%) SpO₂ increased the average risk of mortality by 28 per 1000 infants treated.  
• Term infants were previously believed to require higher SpO₂/PaO₂ to avoid PPHN. However, ‘maintaining higher than normal blood oxygen content has not been scientifically shown to confer any additional benefits, and may be potentially harmful’  

A. Jain, P.J. McNamara / Seminars in Fetal & Neonatal Medicine. 2015
Weaning and Spontaneous Breathing Trial (SBT)

- Are the reasons for intubation resolved?
- Total RR above set RR? Reducing the ventilator rate during PC (with or without VG) has no effect on delivered rate unless respiratory effort is poor or the set RR is greater than the infant’s breathing rate
- Perform an SBT
FIGURE 1
SickKids NICU ERT Protocol. CPAP, continuous positive airway pressure; ABG, arterial blood gas; ETT, endotracheal tube; FiO₂, fractional inspiratory oxygen; HR, heart rate; PaCO₂, partial pressure of arterial carbon dioxide; PEEP, positive end expiratory pressure; PIP, positive inspiratory pressure; PS, pressure support; RR, respiratory rate; SBT, spontaneous breathing trial; VG, volume guarantee; Vt, tidal volume.

Intubated Infant

Assessment of SBT eligibility
- Ventilator settings: RR ≤ 45/minute, PEEP ≤ 7cmH₂O, FiO₂ ≤ 0.40, PIP ≤ 25cmH₂O, VG ≤ 3.5-6ml/kg
- Resolution of disease process
- Clinical status: stable vital signs, respiratory efforts initiated, ABG pH> 7.25, PaCO₂ 35-55mmHg
- Suck/gag/cough reflex present

Eligible

2-Stage SBT
3 minutes ETT CPAP THEN
7 minutes CPAP + PS 5-8 cmH₂O (to achieve spontaneous Vt ~ 4ml/kg)

Successful SBT
- Discuss result with medical team as soon as possible
- Establish extubation plan

Exubation (within 1 hour of SBT)

SBT failure
At least one of:
- HR decreased > 20% of baseline, > 5 seconds
- Apnea
- SpO₂ decreased beyond appropriate range or as ordered by physician (despite 0.15 increase in FiO₂)
- Increased work of breathing

Not eligible
- Continue with care plan
- Re-assess SBT later in the day

Place back on ventilator with settings according to patient's status
- Discuss SBT result with medical team
- Re-assess SBT later in the day
KEY TAKE HOME MESSAGES

Volume-targeted ventilation is the current standard of care for neonatal ventilation

PEEP titrated to optimal level for compliance and oxygenation that avoids over-distension

Pay attention to your TcPCO2 monitor!!

When ready, extubate to non-invasive support if required and minimize any delays
THANK YOU!!