‘From Art to Science’
Old and new concepts in the application of high frequency oscillatory ventilation

Day 2
Session 1: Optimising the application of HFOV
What is an optimal Paw strategy? A physiological rationale  Anastasia Pellicano
Monitoring and Volume Guarantee  David Tingay
Pulmonary circulation and lung recruitment – experimental evidence  Graeme Polglase
Endotracheal tube suction  Andreas Schibler

HIGH-FREQUENCY VENTILATION: VOLUME GUARANTEE AND OTHER NEW CONCEPTS

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Optimising care of the neonate with lung disease

Sailing Between Scylla and Charybdis

Atelectasis
Sheer Force Injury

Volutrauma
Barotrauma

Biotrauma
Oxidative Injury

NAVIGATION TOOLS

Determinants of Gas Exchange

OXYGENATION
Lung Volume
Volume State
FiO2
V/Q mismatch

VENTILATION
Minute Ventilation
Volume State (C_{RS})

P_{aw}

Freq
V_T (ΔP)
P_{aw}
Monitoring Ventilation during HFOV

VENTILATION

- Minute Ventilation
- Freq
- $V_T$ ($\Delta P$)
- Volume State ($C_{RS}$) $\rightarrow P_{aw}$

SM3100
- No active physiological feedback
- (Florian Monitor – Scalfaro 2001)
- Indirect monitoring of CO$_2$

Modern HFV
- Realtime AO feedback
- Flow, $V_T$, ‘DCO’

$C_{RS}$ – NO (practically) due to the complexity of the pressure – flow waves

Monitoring during HFOV

- TcCO$_2$ is reliable during HFOV in infants
- Position is important
  - Well perfused site (chest/shoulder)
  - Visible (burns)
- Know your device
  - Calibration
  - Operating temperatures effects reliability
  - Risks include burns
- TcCO$_2$ mandated at RCH during HFOV
Monitoring during HFOV

Ventilation

- \( V_T/V_{D2} \)
  - NOT a direct measure of Alveolar CO\(_2\)
  - Reliable proxy or trend (usually)
  - Numbers meaningless

- DCO/MV\(_{HF}\)
  - As per \( V_T^2 \)
  Tingay et al CCM 2013

- EtCO\(_2\)
  - Not enough time for Alveolar Plateau
  - Tidal volumes too small (even for mainstream devices)
  - Large deadspace at airway opening

Monitoring during HFOV

DCO

- DCO = Diffusion coefficient of CO\(_2\) at an Alveolar Level
- A mathematical measure of Alveolar Minute Ventilation = \( f \times V_T^2 \)
- Displayed value meaningless and DCO will vary for every baby according to lung size, disease and frequency
- Practically an easier value to interpret than \( V_{THF} \) at the bedside but if Frequency constant both are the same

Tingay et al CCM 2013
PV relationship influences lung mechanics

Distinct relationship between $P_{aw}$ & $V_L$ and $TcCO_2$, $V_T$ & MV

Each optimised on the deflation limb 2 – 4 cmH$_2$O before $P_{close}$

$P_{opt}$ could be predicted

$y = ax + bx^2 + cx^3$ (+dx^4)

The use of modern monitoring allows refinement of the optimal region of ventilation

The reverse is true – the state of the lung may alter mechanics and thus Amplitude needed to optimise CO$_2$ clearance
HFV + Volume Guarantee

- Continuous regulation of oscillatory amplitude to compensate for dynamic changes in the respiratory system
- Potentially fewer periods of hyperventilation and faster weaning
- What is the right VG setting in HFOV?
- We don’t know but it won’t be a single value!

<table>
<thead>
<tr>
<th>Wt (kg)</th>
<th>5 Hz 2.83 mL/kg</th>
<th>10 Hz 2.0 mL/kg</th>
<th>15 Hz 1.63 mL/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>160</td>
<td>160</td>
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</tr>
<tr>
<td>3</td>
<td>360</td>
<td>360</td>
<td>359</td>
</tr>
</tbody>
</table>

Data courtesy Jane Pillow

Targeting $V_T$ is more complicated than on CMV

Tidal volume, Fr and Compliance

Tidal volume increases with:

- Increasing compliance (esp at low Hz)
- Increasing ETT ID

No single $V_T$ (range) can be considered optimal during HFV

Pillow et al AJRCCM 2001
Changes in \( V_{T,hf} \) setting caused appropriate changes in \( r\text{a}_\text{CO}_2 \)

Preterm infants in progress:

1. HFOV vs HFOV+VG crossover: No difference in PCO\(_2\), FiO\(_2\), DP, \( V_{T,hf} \), DCO but hypocarbia 36\% (VG) vs 23\%.
2. PAS 2014: 2 mL/kg \( V_{T,hf} \) a reasonable starting setting (VN500)

A non-evidence based practical approach to HFO+VG

- Start HFOV without VG but with monitoring
- Set Freq for disease, size and device

Adjust \( \Delta P \) for chest wiggle and TcCO\(_2\)

- When TcCO\(_2\) stable (ideally with abg) set VG to deliver current \( V_t \) at that \( \Delta P \) (limit +5 cmH\(_2\)O)
- Note ‘DCO’ values

Low \( V_t \) alarm
Check Patient +/- need to increase \( \Delta P \)

If Freq changed alter set \( V_t \) to maintain stable DCO

Adapted from Jane Pillow
Monitoring Oxygenation during HFOV

OXYGENATION

Lung Volume
Volume State
FiO₂
V/Q mismatch

Paw
Optimising lung volume during HFOV optimises alveolar surface available for gas exchange

\[ P_{AW} = \text{Lung Volume} = \text{PaO}_2 \]

Relationship between \( P_{AW} \), Lung Volume and \( \text{SpO}_2 \)

\[ \text{SpO}_2 \text{ reliably identified TLC (overdistension) and CCP (collapse)} \]


Miedema J Peds 2011

Tingay AJRCCM 2006
**Lung – Ventilator Interaction**

- Oxygenation is a summary of the overall volume state of the lung (and perfusion)
- Assuming that the response to ventilation is uniform within the lung overly-simplifies reality
- Imbalances in the volumetric behaviour of lung regions results in Ventilator-Induced Lung Injury

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**Electrical Impedance Tomography**

- Cross-sectional ‘single slice’ recording
- 16 AgCl electrodes around the chest
- Software can generate a $32 \times 32$ matrix of $\Delta Z$ at different frequencies for regional comparisons
- Allows real-time radiation-free visualisation of relative EEV, $V_T$, Lung Mechanics and perfusions

Figure adapted from Pillow et al. Ped Pul 2008
Using EIT in the ICU
Short-term monitoring of high risk interventions

Endotracheal Tube (ETT) Intubation

- ETT malposition is frequent
- Incorrectly placed ETT is a dangerous complication
- Chest Xray (Gold Standard) is not ideal
- Most bedside tools aim to identify Oesophageal ETT
EIT to guide PAW settings during HFOV

Miedema et al J PEds

Table II. Inflection points based on changes in impedance and oxygenation during both inflation and deflation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LIP (mmHg)</th>
<th>UIP (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>SpO₂</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>(%)</td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>11.0 ± 2.3</td>
<td>15.4 ± 2.2</td>
</tr>
<tr>
<td>Final</td>
<td>10.4 ± 1.9</td>
<td>17.6 ± 1.9</td>
</tr>
</tbody>
</table>

All values are mean ± SD; n refers to number of patients.

The new EIT – anatomically correct imaging
Summary

• Monitoring of parameters that approximate lung mechanics are now routinely available but not infallible and how to interpret is unknown
• Targeting of $V_T$ theoretically provides a mechanisms of stabilising $\text{PaCO}_2$ but the guidelines need validating
• New methods of real-time volume monitoring are on the horizon and in animal studies hold promise
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