Pediatric ventilation updates

F Veyckemans
BAPA - SKA RC
Leuven, January 2018
No conflict of interest
Outline

• Lung protective ventilation ?
• The details that count
• One-lung ventilation
Principle: lung protective ventilation?

Aim: avoiding Ventilator Induced Lung Injury (VILI)
- volotrauma
- barotrauma
- atelectrauma

Low Vt + PEEP?
- some evidence in adults with ARDS
- transposed to adults in OR
- adopted in children but no evidence
Pressure-controlled ventilation

- better lung recruitment
- no risk of barotrauma
- more effective if small leak around TT
- but variable Vt
Volume-controlled ventilation

- risk of barotrauma
- reliability of target volume < 20 ml?
Pressure-controlled volume-guaranteed

= autoflow, pressure-regulated volume control

• breath-to-breath measure of lung compliance
• subsequent PIP modified accordingly
= mix of PC and VC ventilation

➢ risk of important variations in Vt when compliance changes
➢ may not work if leak around Ttube
Pressure-support

- ideal with SGAW for short procedure
- usable during inhalation induction
- preserves spontaneous ventilation
- limits decrease in FRC
- risk of autotriggering if trigger settings too low
Importance of PEEP

- necessary to counteract loss of FRC caused by GA
- keeps lower airway open and decreases atelectasis
- increases lung compliance
  50% in neonates & infants (6cm H$_2$O)
  25% in children
Which ventilator?

1) compensation of the compliance of the breathing system?

2) any interaction between FG flow and VT?
Effect of uncompensated breathing system compliance

Example: 7 kg vs 20 kg

circuit 4 ou 0.7 mL/cmH$_2$O

$V_t = 8$ mL/kg  PIP = 18 cmH$_2$O

V$_t$ + circuit

• 7 kg  circuit :  56 + (18 x 4) = 128 mL  
  circuit :  56 + (18 x 0.7) = 69 mL

• 20 kg  circuit :  160 + (18 x 4) = 232 mL  
  circuit :  160 + (18 x 0.7) = 173 mL
Effect of compensated breathing system compliance

Example: 7 kg vs 20 kg

circuit 4 or 0.7 mL/cmH₂O

Vt = 8 mL/kg  PIP = 18 cmH₂O

\[ Vt + \text{circuit} \]

• 7 kg circuit: \( 56 + (18 \times 4) = 128 \text{ mL} \)

• 20 kg circuit: \( 160 + (18 \times 0.7) = 173 \text{ mL} \)
Interaction FGF with set Vt

In most old ventilators

\[ \text{administered MV} = \text{set MV} + (\text{FGF} \times \text{I/I+E}) - (\text{vol compliance} \times \text{RR}) \]

Modern ventilators:

interruption or diversion of FGF during Insp
<table>
<thead>
<tr>
<th></th>
<th>FGF L/min</th>
<th>1.5</th>
<th>3</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>MV infant</td>
<td></td>
<td>2.12 ± 0.1</td>
<td>2.42 ± 0.2</td>
<td>2.93 ± 0.3</td>
</tr>
<tr>
<td>child</td>
<td></td>
<td>5.02 ± 0.3</td>
<td>5.36 ± 0.3</td>
<td>6.07 ± 0.3</td>
</tr>
<tr>
<td>PIP infant</td>
<td></td>
<td>20.3 ± 1.3</td>
<td>23.1 ± 1.1</td>
<td>27.8 ± 1.3</td>
</tr>
<tr>
<td>child</td>
<td></td>
<td>17.8 ± 0.5</td>
<td>19.4 ± 0.4</td>
<td>22.2 ± 0.5</td>
</tr>
<tr>
<td>$E_{\text{TCO}_2}$ infant</td>
<td></td>
<td>42.1 ± 2.4</td>
<td>37.4 ± 1.5</td>
<td>31.2 ± 1.3</td>
</tr>
<tr>
<td>child</td>
<td></td>
<td>38.9 ± 2.0</td>
<td>36.9 ± 1.6</td>
<td>33.1 ± 1.8</td>
</tr>
</tbody>
</table>
Which ventilator?

1) compensation of the compliance of the breathing system?

2) any interaction between FG flow and Vt?

Pre-use test with all components!
No compensation for leak around Ttube
Limit equipment deadspace!

- The smaller the child, the greater the impact of deadspace.
- Increased deadspace increases gradient between \( \text{paCO}_2 \) and \( \text{EtCO}_2 \).
Heat-moisture exchangers

<table>
<thead>
<tr>
<th>Model</th>
<th>Sidestream</th>
<th>$V_t$ range (mL)</th>
<th>Dead space (mL)</th>
<th>Humidity (mg H₂O/L)</th>
<th>Resistance (cm H₂O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teleflex</td>
<td>Y</td>
<td>50-250</td>
<td>13</td>
<td>30 @ $V_t$ 100</td>
<td>1.4 @ 20 LPM</td>
</tr>
<tr>
<td>Gibeck Humid-Vent filter pedi</td>
<td>Y</td>
<td>15-50</td>
<td>2.4</td>
<td>30 @ $V_t$ 20</td>
<td>0.9 @ 10 LPM</td>
</tr>
<tr>
<td>Humid-Vent mini</td>
<td>N</td>
<td>50-600</td>
<td>10</td>
<td>30.5 @ $V_t$ 200</td>
<td>0.3 @ 20 LPM</td>
</tr>
<tr>
<td>Humid-Vent 1</td>
<td>N</td>
<td>50-600</td>
<td>14</td>
<td>30.5 @ $V_t$ 200</td>
<td>0.3 @ 20 LPM</td>
</tr>
<tr>
<td>Humid-Vent 1 Port</td>
<td>Y</td>
<td>10-50</td>
<td>2</td>
<td>30 @ $V_t$ 25</td>
<td>1.8 @ 15 LPM</td>
</tr>
<tr>
<td>AQUA+ N</td>
<td>N</td>
<td>75-1K</td>
<td>15</td>
<td>24 @ $V_t$ 500</td>
<td>0.2 @ 60 LPM</td>
</tr>
<tr>
<td>AQUA+ T</td>
<td>N</td>
<td>&gt;25</td>
<td>17</td>
<td>27 @ $V_t$ 25</td>
<td>1.2 @ 11 LPM</td>
</tr>
<tr>
<td>Clear-Therm MicroHMEF w/ elbow</td>
<td>Y</td>
<td>&gt;75</td>
<td>34</td>
<td>32 @ $V_t$ 250</td>
<td>2 @ 30 LPM</td>
</tr>
<tr>
<td>Clear-Therm MicroHMEF (no elbow)</td>
<td>Y</td>
<td>&gt;75</td>
<td>28</td>
<td>32 @ $V_t$ 250</td>
<td>1.6 @ 30 LPM</td>
</tr>
<tr>
<td>Clear-Therm MiniHMEF w/ elbow</td>
<td>Y</td>
<td>&gt;75</td>
<td>28</td>
<td>30 (no $V_t$ reported)</td>
<td>2.1 @ 30 LPM</td>
</tr>
<tr>
<td>Clear-Therm MiniHMEF (no elbow)</td>
<td>Y</td>
<td>&gt;75</td>
<td>29</td>
<td>30 (no $V_t$ reported)</td>
<td>2.2 @ 30 LPM</td>
</tr>
<tr>
<td>Inter-Therm Mini Pediatric HMEF</td>
<td>Y</td>
<td>&gt;75</td>
<td>28</td>
<td>30 (no $V_t$ reported)</td>
<td>2.1 @ 30 LPM</td>
</tr>
<tr>
<td>Inter-Therm Mini HMEF angled</td>
<td>Y</td>
<td>&gt;75</td>
<td>29</td>
<td>30 (no $V_t$ reported)</td>
<td>2.2 @ 30 LPM</td>
</tr>
</tbody>
</table>

Optimal management of apparatus dead space in the anesthetized infant

2017; 27: 1185-92
Airway pressure

Pressure measured by the ventilator
= pressure in the whole system
= f resistance of
  circuit: \( \varnothing \), length, compliance, adds on
  Ttube: \( \varnothing \), kinking, secretions
  patient’s lungs: bronchospasm, external compression

no magic number: look at the child!
Monitor the results

- thoracic movement
- auscultation
- SpO$_2$ vs FiO$_2$

- EtCO$_2$: distal sampling
  - there is always a difference with PaCO$_2$
  - it is unpredictable:
    if possible check with Pa or Pv or transcutaneous CO$_2$
Pressure-volume loops
• 26 neonates 3167 g ± 736 under GA
2015 Melbourne
16 laparotomies
ventilated with Aisys® GE
• ventilation settings: anesthesiologist in charge
• respiratory function monitor (Florian ®)
automatic recording of data
Results (1)
Aisys® GE overestimated expired Ve by a mean bias of 3 ml/kg (-4.5 to 10.8 !) because measured close to the expiratory valve of the circuit rather than at the airway connection.
Tricks

- I/E: 1/1.5 can be better than 1/2: right volume!

- avoid high RR: risk of autoPEEP
  spurious rebreathing on capnogram

- beware of expired volume measured
  in neonates & small infants
  intubated with uncuffed tubes
  pressure-control with PEEP
40 infants < 1 y, ASA 1-2
Intubated with uncuffed TT, paralysed
FiO₂ 0.4, Vt 8 ml/kg, RR 20-40, I:E 1:2, PEEP 5 cm H₂O
Pulmonary US of each hemithorax divided in 6 zones
- 1 min after starting ventilation
- at the end of surgery

20: recruitment maneuver under US control after 1ˢᵗ US examination
<table>
<thead>
<tr>
<th>Recruitment Manoeuvre group</th>
<th>Control group</th>
</tr>
</thead>
<tbody>
<tr>
<td>p value*</td>
<td>p value†</td>
</tr>
<tr>
<td><strong>First ultrasound examination</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Consolidation score</strong></td>
<td></td>
</tr>
<tr>
<td>In the anterior regions</td>
<td></td>
</tr>
<tr>
<td>11.0 (8.0–15.0 [3.0–21.0])</td>
<td>10.0 (8.0–12.3 [3.0–20.0])</td>
</tr>
<tr>
<td>2.5 (1.8–3.0 [0.0–4.0])</td>
<td>3.0 (2.0–4.0 [0.0–4.0])</td>
</tr>
<tr>
<td>3.0 (2.0–4.0 [0.0–6.0])</td>
<td>3.5 (2.0–4.0 [0.0–6.0])</td>
</tr>
<tr>
<td>5.0 (4.0–9.0 [0.0–12.0])</td>
<td>4.0 (3.0–6.0 [1.0–12.0])</td>
</tr>
<tr>
<td><strong>B-lines score</strong></td>
<td></td>
</tr>
<tr>
<td>In the anterior regions</td>
<td></td>
</tr>
<tr>
<td>12.0 (8.0–16.0 [4.0–29.0])</td>
<td>11.5 (8.0–13.5 [1.0–20.0])</td>
</tr>
<tr>
<td>2.5 (1.0–4.0 [1.0–8.0])</td>
<td>3.0 (2.0–4.0 [0.0–5.0])</td>
</tr>
<tr>
<td>3.5 (1.8–4.0 [0.0–10.0])</td>
<td>3.0 (2.8–4.0 [0.0–6.0])</td>
</tr>
<tr>
<td>6.5 (4.0–8.3 [1.0–12.0])</td>
<td>5.0 (3.8–7.0 [0.0–11.0])</td>
</tr>
<tr>
<td><strong>Second ultrasound examination</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Consolidation score</strong></td>
<td></td>
</tr>
<tr>
<td>In the anterior regions</td>
<td></td>
</tr>
<tr>
<td>6.0 (3.0–9.3 [0.0–14.0])</td>
<td>13.5 (11.0–16.5 [8.0–23.0])</td>
</tr>
<tr>
<td>1.0 (0.0–3.3 [0.0–4.0])</td>
<td>4.0 (2.8–4.0 [2.0–4.0])</td>
</tr>
<tr>
<td>1.5 (1.0–3.0 [0.0–4.0])</td>
<td>4.0 (4.0–4.3 [2.0–7.0])</td>
</tr>
<tr>
<td>3.0 (2.0–4.3 [0.0–6.0])</td>
<td>6.0 (4.0–9.3 [3.0–12.0])</td>
</tr>
<tr>
<td><strong>B-lines score</strong></td>
<td></td>
</tr>
<tr>
<td>In the anterior regions</td>
<td></td>
</tr>
<tr>
<td>6.5 (3.0–12.0 [0.0–28.0])</td>
<td>15.0 (10.8–20.5 [7.0–28.0])</td>
</tr>
<tr>
<td>1.0 (1.0–3.3 [0.0–8.0])</td>
<td>4.0 (2.8–5.0 [2.0–7.0])</td>
</tr>
<tr>
<td>2.0 (0.8–3.0 [0.0–9.0])</td>
<td>4.0 (3.0–5.3 [1.0–9.0])</td>
</tr>
<tr>
<td>3.0 (2.0–6.0 [0.0–11.0])</td>
<td>6.5 (4.8–11.0 [2.0–12.0])</td>
</tr>
</tbody>
</table>

*First vs. second ultrasound examination in the recruitment manoeuvre group.
†First vs. second ultrasound examination in the control group.
‡Recruitment manoeuvre group vs. control group.
When recruiting?

- after any event that may cause a loss in FRC
  - disconnection from circuit
  - suction in TT

- after extubation: CPAP by mask immediately
One-lung ventilation

Indications:
- **absolute**: protection of other lung
  * unilateral infection
  * unilateral hemoptysis
  * lung lavage for alveolar proteinosis
- **relative**
  * thoracic surgery (tomy /scopy): surgeon’s needs
  * decompression of unilateral pulmonary emphysema
Tracheal anatomy in children

Lower airway dimensions in pediatric patients—A computed tomography study

Patricia Szellöe¹² | Markus Weiss¹⁴ | Thomas Schraner³⁴ | Mital H. Dave¹³

<table>
<thead>
<tr>
<th>Age (y)</th>
<th>Patients (n=195)</th>
<th>Boys/Girls (n=118/77)</th>
<th>Intubated/not intubated (n=54/141)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>18</td>
<td>10/8</td>
<td>13/5</td>
</tr>
<tr>
<td>1-2</td>
<td>20</td>
<td>16/4</td>
<td>13/7</td>
</tr>
<tr>
<td>2-4</td>
<td>34</td>
<td>21/13</td>
<td>18/16</td>
</tr>
<tr>
<td>4-6</td>
<td>18</td>
<td>11/7</td>
<td>4/14</td>
</tr>
<tr>
<td>6-8</td>
<td>21</td>
<td>11/10</td>
<td>2/19</td>
</tr>
<tr>
<td>8-10</td>
<td>23</td>
<td>10/13</td>
<td>2/21</td>
</tr>
<tr>
<td>10-12</td>
<td>19</td>
<td>17/2</td>
<td>1/18</td>
</tr>
<tr>
<td>12-14</td>
<td>19</td>
<td>9/10</td>
<td>0/19</td>
</tr>
<tr>
<td>14-16</td>
<td>23</td>
<td>13/10</td>
<td>1/22</td>
</tr>
</tbody>
</table>

*Pediatr Anesth 2017;27:1043-9*
Classic view: the younger, the more vertical & wider the right bronchus
Lateral Decubitus Ventilated

- Non-depandan lung further ↑ V/Q
  - ↓Q due to gravity
  - ↑V due to position on compliance curve
  - Further ↑V if chest opened
- Dependant lung further ↓ V/Q
  - ↑Q due to gravity
  - ↓V due to
    - Position on compliance curve
    - Loss of diaphragm advantage
    - Greater impact of abdominal contents and mediastinum
    - Sub-optimal positioning
One lung ventilation physiology (1)

- hypoxic pulmonary vasoconstriction
  - large interindividual variability
  - onset and offset are progressive
    (interest of preconditioning ?)
  - dose-dependent inhibition by halogenated
    but if < 1 MAC = IV agents

- animal models:
  perfusion of blocked lung $\downarrow$ by 50%
  but HPV is only responsible for 50% of it
One lung ventilation physiology (2)

- **ventilated lung**: 💥 overinflation!
  - = ☢️ cytokines, oxidative stress
  - avoid > 5 ml/kg, high PIP (but ☢️ resistance to flow !)
    - high FiO$_2$, long duration

- **blocked / collapsed lung**: surgical trauma +
  1) recruitment after collapse: ☢️ cytokines
  2) ischemia-reperfusion injury: oxidative stress

CPAP during blocking period

low FiO$_2$ and gentle pressure during recruitment
One lung ventilation physiology (2)

- ventilated lung: ♦ overinflation!
  - cytokines, oxidative stress
  - avoid > 5 ml/kg, high PIP (but resistance to flow!)

OLV
- is non-physiologic
- can produce damage to both lungs
- only if required
- as short duration as possible

- recruitment after collapse:
  - cytokines
- ischemia-reperfusion injury:
  - oxidative stress
- CPAP during blocking
- low FiO₂ and gentle pressure during recruitment
Protective effect of sevo against reperfusion injury?

Methylprednisolone 2 mg/kg
given 30 min prior to lung collapse
- decreases inflammatory reaction: ↓IL6 ↑IL10
- decreases reperfusion injury: ↓Tryptase
- reduces increase in lung dynamic resistance after OLV

# How to achieve OLV

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Tracheal tube ID (mm)</th>
<th>Fogarty® (Fr)</th>
<th>Arndt® (Fr)</th>
<th>Swan-Ganz (Fr)</th>
<th>Univent®</th>
<th>Double lumen (Fr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5-1</td>
<td>3.5-4</td>
<td>3</td>
<td>5 (lat)</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-2</td>
<td>4-4.5</td>
<td>4</td>
<td>5 (lat)</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-4</td>
<td>4.5-5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-6</td>
<td>5-5.5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6-8</td>
<td>5.5-6</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td></td>
<td>3.5</td>
</tr>
<tr>
<td>8-10</td>
<td>6 + cuff</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>3.5</td>
<td>26</td>
</tr>
<tr>
<td>10-12</td>
<td>6.5 + cuff</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>4.5</td>
<td>26-28</td>
</tr>
<tr>
<td>12-14</td>
<td>6.5-7 + cuff</td>
<td>6</td>
<td>9</td>
<td>7</td>
<td>4.5</td>
<td>32</td>
</tr>
<tr>
<td>14-16</td>
<td>7 + cuff</td>
<td>7</td>
<td>9</td>
<td>7</td>
<td>6</td>
<td>35</td>
</tr>
</tbody>
</table>
< 2-3 years

fiberscope

blocker
Home-made blockers

Swan-Ganz catheter: 5 or 7F

Fogarty embolectomy catheter 3, 4 or 5F ideally Thru-lumen®
Arndt blocker

5 Fr : 0.5 – 2 ml
7 Fr : 2 – 6 ml
9 Fr : 4 – 8 ml
Extraluminal Arndt blocker

Parallel Extra-Luminal Placement of Arndt Endo-Bronchial Blocker
Univent® tube

- 3.5: uncuffed
  no central lumen in blocker
  OD 7.5 - 8 mm
  ~ 5.5 - 6.0 Ttube
- 4.5: cuffed
  OD 8.5 - 9 mm
  ~ 6.5 Ttube
Measured intracuff pressure does not reliably reflect pressure on the bronchial mucosa
In vitro: external pressure vs volume

![Graph showing the relationship between external pressure and volume with different lines representing different conditions. There is a note indicating the mucosal ischemic threshold.](image-url)
Double lumen tubes

- from 8 years
- smallest 26 Fr: OK if > 30 kg and > 130 cm
- size ~ age x 1.5 +14
- usually left-sided
Control of position

- fiberoptic bronchoscopy
- image intensifier (X-ray): carina, diaphragm mvt.
- auscultation
Ventilating on one lung

- limit IV fluids: keep on the dry side
- corticoids:
  2 mg/kg methylprednisolone before lung collapse
- maintain reflex hypoxic vasoconstriction
- halogenated: max 1 MAC and start soon!
- mild hypercapnia (paCO$_2$ 40-60 mmHg)
  small $V_t$ ($\leq$ 5 ml/kg) + increased RR + PEEP
- at the end: gentle recruitment maneuver with low FiO$_2$
Difficult ventilation?

- During OLV:
  - blocker slipped into the trachea?
  - Ttube blocked by secretions, blood?
  - bronchospasm?

- After OLV:
  - Ttube blocked by secretions, blood?
  - pneumothorax?
Suggested readings

**Optimal Ventilation of the Anesthetized Pediatric Patient**
Jeffrey M. Feldman, MD, MSE

*Anesth Analg* 2015; 120: 165-75

**Lung Injury After One-Lung Ventilation: A Review of the Pathophysiologic Mechanisms Affecting the Ventilated and the Collapsed Lung**
Jens Lohser, MD, MSc, FRCPC,* and Peter Slinger, MD, FRCPC†

*Anesth Analg* 2015; 121: 302-18
A new era?

Transnasal humidified rapid-insufflation ventilatory exchange (THRIVE) in children: a randomized controlled trial†

S. Humphreys1,2, P. Lee-Archer1,2, G. Reyne1,3, D. Long1,3,4, T. Williams1,3 and A. Schibler1,3∗
THRIVE: what is it?

n = 48 children < 10y
induction of anesthesia
paralyzed
bag-mask ventilation FiO₂ 1
after 3 min:
- apnea with jaw-thrust
  ⇒ time to SpO₂ 92% = †
- Optiflow® + jaw-thrust
  2L/kg/min if < 15 kg
  35L/min if 15-30 kg
  ⇒ stop when 2 × †
At least double safe apnea time

Stopped by protocol at 2 x control time

New option for difficult intubation / ventilation?
ESPA/IAPA CONGRESS

ESPA – European Society for Paediatric Anaesthesiology

IAPA – International Assembly for Pediatric Anesthesia

“Excellence Knows No Borders”

September 6–8, 2018
Hotel Le Plaza: Brussels, Belgium
www.euroespa.com

Endorsed by: