What can I do with my New Anaesthetic Ventilator?

Chris Thompson
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Which of the following are true?

- Modern machines are easy to breathe through
- Lung collapse under GA is uncommon
- ICU ventilation modes aren’t needed
- Volume Control IPPV is still the best
- 10 ml/kg * 10 with I:E 1:2 is just about right
- Rotameters and a bellows are essential
- Can’t breathe on the bag = intubation
Anaesthesia vs ICU ventilators

- Very basic compared to those in ICU
- ICU ventilation concepts (mask CPAP, PS, Open Lung, Recruitment, Low Volume High Rate) uncommon in anaesthetic practice
- Anaesthetists been more interested in better drugs and monitoring than ventilation.
Ventilation problems are common...

- Saturations of 91 in recovery
- See-saw / inadequate respiration with LMA’s
- Inadequate ventilation requiring assistance
- High airway pressures on IPPV
- Post-operative pulmonary morbidity
- Hit or miss weaning from IPPV
- Patients who say “I can’t breathe on a mask”
A recent review...

Oxygenation is impaired in almost all subjects during anesthesia... hypoxemia for shorter or longer periods is a common finding.

Postoperative lung complications occur in 3-10% after elective abdominal surgery and more in emergency operations.

Rapid collapse of alveoli on induction of anesthesia and more widespread closure of airways seem to explain the oxygenation impairment... this may also contribute to postoperative pulmonary infection.

How could a better ventilator help?

- Patient comfort during pre-oxygenation
- An extra hand to squeeze the bag
- Support for inadequate respiration
- Prevention and Rx of lung collapse
- Reduced alveolar shear stress
- Smart weaning
- Reliability and Accuracy
Spontaneous Breathing Support

= Minimising Work of Breathing

• Work = Force x Distance
  ie Pressure x Volume

• The more negative the patient’s inspiratory effort (intrapleural pressure), the greater the work performed.
Work of breathing factors

Two main components:

1. Elastic work (overcoming lung stiffness)

2. Air Flow work (overcoming resistance)

Both contribute equally to total work in normal lungs

NB: normal respiratory rate is 15; faster with stiff lungs, slower for airway resistance
Work of breathing during anaesthesia

• Circuit Resistance: work ↑ by 50%
  Due to resistance of ETT, APL, absorber, tubing, valves etc.

• Anaesthesia per se
  ↓ FRC → ↓ compliance & ↑ resistance → ↑ work

• Can be 2 – 6 times more difficult than normal!
  Poorly tolerated by some patients
  upper airway obstruction
  tachpnoea, see-saw respiration
  expiratory push
Machine components and resistance

- Resistance increases negative airway pressures at the Y-piece.
- With ETT, most circuits exceed Nunn’s maximum safe pressure drop 3.0 cm H₂O @ 30 l/min.
- Expiratory resistance after the bag fills (APL valve) as well.

<table>
<thead>
<tr>
<th>Part</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 m circle system*</td>
<td>2.5</td>
</tr>
<tr>
<td>7 – 8 ETT</td>
<td>2.0 – 3.5</td>
</tr>
<tr>
<td>APL (bag full) **</td>
<td>&gt; 2</td>
</tr>
<tr>
<td>TOTAL</td>
<td>&gt; 5</td>
</tr>
</tbody>
</table>

Resistance to flow, cm H₂O at 30 l/min
- * including valves etc
- ** fully open; depends on type

NB: Normal PiFR ≈ 30 l/min → 10 cm H₂O intrapl. press. drop
Work due to anaesthesia itself

- FRC ↓ by ≈ 400ml, causing:
  - ↑ resistance (≈ doubles) → 2x air flow work
  - ↓ compliance (≈ half) → 2x elastic work
- Net effect is to quadruple the work of breathing
- Minimised if ↓FRC is prevented or treated.

Lung volume reduction and resistance from Nunn 2ndEd Fig 43
Minimising work of breathing

- Maintain FRC / Prevent lung collapse
  - recruit
  - use optimal PEEP

- Minimise circuit resistance
  - larger ETT / LMA diameters
  - ICU-circuit-type machines

- Assist spontaneous ventilation
  - learn how to use “Pressure Support” ...
Pressure Support ventilation

- “Smart” assistance for spontaneous respiration
- Adds airway pressure on inspiration
  - Inspiratory time auto-adjusts to suit the patient
  - PEEP / CPAP can be added
  - Added safety of fallback ventilation on apnoea
- Like the ‘educated hand’ only better!
- Improves tidal volumes, lowers CO$_2$
Pressure Support details - overview

Pressure Support breaths

Flow
(Pressure Control mode)
l/min

Pressure
(cm H2O)

Inspiration
Expiration

Pressure Support activated

Time (seconds)

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Pressure Support - Synchronisation

- Automatic sync
- Insp. Trigger: flow +/- pressure
- Must be fast and reliable
- Threshold should be adjustable
too low → false triggering on heartbeat
too high → patient effort unsupported

- NB: won’t trigger if obstructed!
Pressure Support : Inspiration

- Set the Insp Pressure:
  start at 5 – 8 cmH₂O, then adjust

- Inspiration ends when either:
  flow falls to 25% of the peak insp. flow rate, or
  an arbitrary maximum time elapses

- Peak flow capability must be very high

- Rise time should be adjustable
  0.3s works well for most people
  faster for children, gasping respiration
Pressure Support: Expiration

- Pinsp drops when patient breaths out
- Patient sets their own respiratory rate
- add PEEP easily
  functionally works like ICU CPAP
- Expiratory resistance should be small
  can be high; best with ICU-type circuit design
Pressure Support – Apnoea

• Transient apnoea is relatively common
e.g. narcotic administration
too much pressure support lowering CO$_2$ (!)

• Automatic “Fall-back” ventilation
intended to assist ventilation
machine self-triggers at a ‘fallback rate’
either uses PS breaths (Dräger) or PCV (GE)
alarm or message
auto-return to PS when apnoea ends (Dräger only)
Clinical applications of Pressure Support

1. Improving ventilation during LMA cases
   
   typical values:
   5-12 cmH\textsubscript{2}O of support,
   with 5-10 cmH\textsubscript{2}O of PEEP if needed

2. Weaning from IPPV

   Fallback rate 7–8
   Enough PS for decent tidal volume
   Enough PEEP to prevent collapse
   Patient weans themselves
3. Induction of anaesthesia

- **Practicalities:**
  - Get a good mask seal
  - Keep flow rates high enough for leaks
  - Go to standby when taking the mask off

- **Settings:**
  - Fallback rate of 15
  - 5 cm H₂O PS while awake
  - On induction, increase to maintain tidal volumes
  - Add PEEP to counter obstruction

- **Like a second person squeezing the bag!**
Lung Collapse / Loss of FRC

- Occurs on induction, continues during case

- Contributing factors:
  
  apnoeic episodes in O₂ or O₂ / N₂O
  obesity, increasing age, – trendelenburg etc (↓ FRC)
  not enough PEEP / CPAP

- Can worsen lung compliance by 30 – 60%
  
  combination of ↓ elasticity & ↑ resistance
  → higher airway pressures, hypoxaemia, increased work of breathing, etc

➡ Post-operative lung dysfunction
Tusman et al, MRI images in children

24 children, 6 months - 6 years having MRI, intubated deep without relaxant then spontaneous respiration on ETT.

3 groups: no PEEP, 5 of PEEP and Recruitment + PEEP.

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Tusman et al 2

MRI images in children
PEEP alone was useless...

Table 2. Atelectatic Volumes

<table>
<thead>
<tr>
<th></th>
<th>ZEEP</th>
<th>CPAP</th>
<th>ARS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atelectasis volume (cm³)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>1.25 (0.75–4.56)*</td>
<td>9.5 (3.1–23.7)</td>
<td>0†‡</td>
</tr>
<tr>
<td>Left</td>
<td>4.25 (3.2–13.9)</td>
<td>8.8 (5.3–28.5)</td>
<td>0†‡</td>
</tr>
</tbody>
</table>

Data are presented as median, first (25%) quartile, and third (75%) quartile.
Significant difference (Mann–Whitney U test) between *ZEEP and CPAP, between †CPAP and ARS, between ‡ZEEP and ARS. All $P < 0.05$.

ARS = alveolar recruitment strategy group; CPAP = continuous positive end-expiratory group; ZEEP = zero end-expiratory pressure group.

NB: ARS = Recruitment to 40/15 for 10 breaths then PEEP
“CPAP” was applied with PEEP valve, ie not true CPAP.
Prevention of Lung Collapse

- Avoid apnoeic episodes
- Perform recruitment manoeuvre/s
  - 35-40 cm H₂O over 15-20 cm H₂O of PEEP
  - hold for 10 breaths or 30s
- Monitor compliance & re-recruit if needed
- Optimise PEEP / CPAP
  - to best lung compliance or best PaO₂ or both
- Use Pressure Mode; optimise Ti and Te
Maintaining ‘open lungs’ post-op

- **Maintain PEEP at all times**
  
  - wean using Pressure Support with PEEP
  - don’t intermittently bag without PEEP
  - don’t leave apnoeicic to induce respiration

- **Recruit the lung just before extubtion**

- **Extubate sitting up**
  
  - ... in as little oxygen as possible
  - ... as awake as possible
  - ... with good analgesia
PEEP ALONE IS NOT ENOUGH
RECRUITMENT IS ESSENTIAL
PEEP SHOULD BE OPTIMISED
What is optimal PEEP?

Optimal PEEP provides best -

• Mechanical compliance
  and/or

• \( \text{PaO}_2 \)

without undue cardiovascular depression
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Typical compliance curves

Optimal mechanical PEEP

Normal

Anaesthesia

Slope ≈ Compliance
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Optimal mechanical PEEP typical values

Typical compliance curves

- Normal
- Anaesthesia

600 ml Vt
normal: 7 cmH2O
anaes: 16 cmH2O
Optimal mechanical PEEP is where compliance is best

Typical pressures for a 600ml breath while anaesthetised

<table>
<thead>
<tr>
<th>PEEP</th>
<th>Pressures</th>
<th>ΔP</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>16/0</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>18/5</td>
<td>13</td>
</tr>
<tr>
<td>10</td>
<td>21/10</td>
<td>11</td>
</tr>
<tr>
<td>15</td>
<td>27/15</td>
<td>12</td>
</tr>
<tr>
<td>20</td>
<td>42/20</td>
<td>22</td>
</tr>
</tbody>
</table>

... optimal PEEP = 10 cmH2O for this patient
**How I determine optimal PEEP...**

- **Use Pressure Control**
- **With PEEP at 0, set:**
  - $\Delta P$ to give adequate $V_t$,
  - I:E ratio 1:1,
  - rate 10 (3s insp)
- **Increase PEEP in steps with same $\Delta$ pressure**
- **Find the PEEP that gives the best tidal volume.**

<table>
<thead>
<tr>
<th>PEEP</th>
<th>$V_t$</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>300</td>
</tr>
<tr>
<td>5</td>
<td>470</td>
</tr>
<tr>
<td>10</td>
<td>550</td>
</tr>
<tr>
<td>15</td>
<td>510</td>
</tr>
<tr>
<td>20</td>
<td>350</td>
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**Optimal mechanical PEEP my way**

$\text{optimal PEEP} = 10 \text{ cmH}_2\text{O}$

for this patient
Then include a recruitment manoeuvre

- Recruit at PEEP of 20 with peak pressures of 35 – 40 for 30s

<table>
<thead>
<tr>
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<tr>
<td>0</td>
<td>300</td>
<td></td>
</tr>
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<td>470</td>
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</tr>
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<td>350</td>
<td>400</td>
</tr>
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</table>
Then include a recruitment manoeuvre and drop down to the starting PEEP

- Recruit at PEEP of 20 with peak pressures of 35 – 40 for 30s
- Return to initial $\Delta P$, dropping back through same PEEP steps

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<tr>
<td>15</td>
<td>510</td>
<td>670</td>
</tr>
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<td>20</td>
<td>350</td>
<td>400</td>
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Best Vt at 10 of PEEP
Then include a recruitment manoeuvre and drop down to the starting PEEP

- Recruit at PEEP of 20 with peak pressures of 35 – 40 for 30s
- Return to initial $\Delta P$, dropping back through same PEEP steps
- Benefit of PEEP + recruitment can be quantified

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Overall compliance doubled
$\approx \frac{1}{3}$ of the lung had collapsed.
Optimal mechanical PEEP: typical result of recruitment

- Markedly improves compliance i.e. Vt at same ΔPaw
- Reduces shear stress for given tidal volume
- Keeps recruited alveoli open

Recruitment ↑ Vt from 300ml to 750ml at same ΔPaw
What is ‘open lung’ ventilation?

• Minimal differential airway pressures
  → reduce shear stress, barotrauma, ARDS

• Techniques:
  Optimal PEEP / CPAP
  Recruitment manouevres
  Optimal inspiratory and expiratory times
  Lower volumes / higher rates
  Permissive hypercapnoea
Lower tidal volumes and higher rates

- Physiologically normal values:
  - Tidal volume: 5 – 7 ml/kg
  - Respiratory rate: 12 – 15 breaths per minute

- 10 ml/kg $\times$ 10 is NOT normal.

- With 50% collapse, Paw increases only 1/3, but the remaining lung tissue gets DOUBLE the effective shear stress

- High shear stress over time induces ARDS
Optimal inspiratory and expiratory times

Flow curves in Pressure Control should never be flat!

No gas flow = No ventilation
Optimal expiratory times

No gas flow = No ventilation

Optimising settings: Te

wasted time in expiration
## Optimal inspiratory and expiratory times

<table>
<thead>
<tr>
<th>time</th>
<th>Inspiration</th>
<th>Expiration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Too short</strong></td>
<td>hypoventilation and collapse of long time constant alveoli → hypoxia, loss of FRC etc</td>
<td>hypoventilation and hyperinflation of long time constant alveoli → hypoxia, reduced compliance, etc</td>
</tr>
<tr>
<td><strong>Too long</strong></td>
<td>tidal volumes need to be larger than usual; increases Paw. doesn’t improve ventilation once gas flow stops, can impair C.O.</td>
<td>tidal volumes need to be larger than usual; enhances collapse. doesn’t improve ventilation once gas flow stops</td>
</tr>
</tbody>
</table>
How can an ‘advanced’ ventilator help me?

- Accurate control, adjustment and display of pressure, flow and volume; Pressure Control modes
  → Ti, Te & PEEP optimisation; recruitment

- Spontaneous breathing support (PS, CPAP)
  → easier LMA anaesthesia, better airway, easier weaning
  → two hands free to hold the mask

- Leak detection +/- compensation; useful alarms

- Automated self-checking & calibration

- Knowing exactly what’s going on
Informative displays - esp flow curves

GE Aisys

Dräger Primus
Aisys circuit

Vent / PS inspiration

Vent / PS expiration
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Circuits: Primus

Primus circuit
What should I look for?

- Low resistance circuit, esp in expiratory phase breathe through it yourself!
- High flow capability (test by breathing fast in PS)
- Crisp waveforms for flow, pressure & CO$_2$
- Clear indication of spont. vs control breaths
- Vt unaffected by FGF
- ‘Mode’ should be obvious
- Trends eg compliance
- Simple Circuit
Conclusions:

1. Lung collapse and ↑ work of breathing are very common during anaesthesia.

2. Optimal PEEP & lung recruitment help a lot.

3. PEEP alone is of little or no benefit.

4. Pressure Support is GREAT!

5. Modern ventilators make a real difference... when we’ve learned how to use them!