Anesthesia Ventilators 101

Featuring the Hallowell 2000

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Why Ventilate?

- Anesthetic agents are respiratory depressants—

  *All anesthetized patients hypoventilate!*

  - Difficulty maintaining $\text{PaCO}_2 < 40$ mmHg

**GOAL:** Maintaining normal $\text{CO}_2$ tensions in arterial blood
Why Ventilate?

- Hypoventilation / apnea / panting
  - Helps maintain stable anesthesia plane
- Gross obesity / Pickwickian
- Prolonged surgical procedures
  - >90 minutes (especially horses)
- Neuromuscular blockers
- Patient positioning
- Lung disease
- Intracranial disease
Why Ventilate?

- Thoracic surgery & trauma
  - Flail chest or diaphragmatic hernia
- Convenience!
Carbon Dioxide Physiology

- CO$_2$ transferred in the body in 3 forms:
  - 60-70% transported as bicarbonate ion
  - 20-30% transported bound to proteins
  - *5-10% dissolved in plasma.

- *Plasma component measured during blood gas analysis as arterial partial pressure of carbon dioxide (PaCO$_2$)
Carbon Dioxide Physiology

Mixed venous

PO₂ = 40
PCO₂ = 46

O₂  CO₂

PO₂ = 102
PCO₂ = 40

End capillary

PO₂ = 102
PCO₂ = 40

Blood flow
Carbon Dioxide Physiology

■ ETCO$_2$ Requirements
  ▪ Blood flow
  ▪ Cellular metabolism
  ▪ Alveolar ventilation

■ Great CPR tool!
Normal ETCO$_2$ Values

<table>
<thead>
<tr>
<th>PaCO$_2$</th>
<th>Condition in blood</th>
<th>State of vent</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 45</td>
<td>Hypercapnia</td>
<td>Hypoventilation</td>
</tr>
<tr>
<td>35-45</td>
<td>Eucapnia</td>
<td>Normal</td>
</tr>
<tr>
<td>&lt; 35</td>
<td>Hypocapnia</td>
<td>Hyperventilation</td>
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</tbody>
</table>
Carbon Dioxide Physiology

- Assess cardiac output secondary to hypovolemia
Carbon Dioxide Physiology…

When $\text{EtCO}_2 \neq \text{PaCO}_2$

- Low pulmonary blood flow
  - Shock / cardiac arrest

- Significant clinical change “delays”
  - Metabolic disorder
  - Pulmonary embolism ($V/q$)
  - Pneumonia/atalectesis ($v/Q$)
Anesthesia Ventilators

- Double circuit units

  - Utilize 2 gas sources

A. Driving gas enters
B. Scavenger
C. Overflow gas from patient circuit
D. Bellows
E. Pop-off valve
F. Tidal volume adjustment
H. Bellows housing
Ventilator Terminology

- **Tidal volume** \((V_T)\)- amount of gas exchanged in one respiratory cycle

- **Minute volume** \((V^m)\)- total amount of gas (in liters) exchanged per minute
  - Dependent on \(V_T\) & breaths per min (BPM):
    \[
    V_T \times \text{BPM} = V^m
    \]
Ventilator Terminology

- **IPPV / IPPB**: Intermittent positive pressure (PP) maintained during inspiration; passive expiration

  Anesthesia machines are *intermittent dosing devices*...?

- **PEEP**: Positive end-expiratory pressure
  - Hallowell vents maintain 5 cm H$_2$O PEEP
  - SurgiVet SAV2500 maintains 2 cm H$_2$O PEEP
Ventilators Simplified:
Know Your Equipment!

- Ensure anesthesia machine is equipped for ventilator accessibility
The Front Panel

Four Basic Controls:

- **I/O Power Switch**: Green light above switch indicates ventilator is ON
- **Rate (BPM)**: Set respiratory rate in breaths per minute
- **Volume (ml)**: Control volume (size) of breath being delivered
- **Maximum Working Pressure Limit (MWPL)**: Set an upper limit above which pressure should not exceed during cycle
  - Set between 20-30 cm H₂O
Ventilator Connections

Ventilator parts:

- **Power Plug**
- **Breathing System:** Clear hose
- **Exhaust:** Blue hose
- **Driving Gas:** Black hose
- **O₂ Hose:** Green hose
Connect Oxygen Supply

- Additional oxygen connection needed on anesthesia machine to allow ventilator access

- Attach ventilator’s loose oxygen hose to open connection

- Tighten oxygen hose to secure
  - Hissing sounds occur when O$_2$ plugged in to supply tanks!
Connect Breathing System

- Follow clear hose (labeled BREATHING SYSTEM) from back of ventilator to unconnected end
- Connect hose to re-breathing bag connection on anesthesia machine
- Ventilator is now a ‘re-breathing bag’
Insert Airway Pressure Sensor

- Connect APST tube to **INSPIRATORY** side of breathing system
  - Small, clear tube connected to a larger male/female connector
  - Confirm inspiratory side with oxygen flush
Connect Wye Hoses

- Attach wye hoses as usual

- APST is now connected between wye hose and anesthetic machine on the **INSPIRATORY** side
Connect Exhaust

2 Options:

- Remove existing scavenging hose

- Connect scavenger to (2nd) open port
  - Remove red cap from port opening first
Plug It In!

- Don’t forget to plug power cord from ventilator into a wall outlet
Pop-off Valve

- Close pop-off valve once ventilator is connected to anesthesia machine
  - Prevents leaks

- It is **very** important to remember to OPEN pop-off valve once ventilator is disconnected!
Check for Leaks

- Occlude end of wye hose
- Turn on oxygen until bellows is completely inflated
- Turn off O₂
- Bellows will stay inflated if no leaks present

Anesthesia machine should be checked for leaks both *before* and *after* connecting ventilator.
Changing Bellows

- **Rule of thumb:**
  - <30 lb = small bellows
  - >30 lb = large bellows
*LEAN BODY WEIGHT ONLY

- Pediatric bellows: 0-300 ml (0.5-15 kg)
- Adult bellows: ≤1500 ml (up to 75 kg)
- Foal bellows: ≤ 3000 ml (up to 150 kg)
Removing Bellows

- Once removed, put bellows housing in a safe place
Fitting Bellows

- Small bellows fits seated onto smaller (inner) ring
  - Large bellows requires outer ring

- Ensure bellows placed on ventilator *circumferentially*
  - Only very bottom of accordion should be attached to ventilator

- **Misplacement will prevent bellows from fully inflating**
Setting Bellows

- Ensure correct placement by gently lifting bellows until last accordion ring is visualized in place
  - Eliminate concaved or folded areas in bellows
Secure Bellows Housing

- Replace corresponding bellows housing
- Firmly secure housing
- Turn only base of housing (not tall area) to avoid damage
Secure Bellows Housing

- Once housing is firmly set, rotate clockwise until housing is locked
  - If housing unit is not properly set, cracked or damaged, a leak may result

- Ensure that volume numbers are visible and facing front of anesthesia machine
Set Maximum Working Pressure Limit (MWPL)

- Typically 20-30 cm H$_2$O
- Safety feature!
Peak Inspiratory Pressure (PIP)

- Lung compliance is important for determining adequate pressure to inflate the lungs. 
  
  \((\text{volume/pressure/kg})\)

- PIP should be between 12 to 30 cm H\(_2\)O

*Never exceed 20 cm of H\(_2\)O without the doctor’s permission or consent!*
MWPL Pressure Alarm

- When MWPL set-point is exceeded ventilator alarms and terminates inspiratory phase of breathing cycle
- When pressure reaches preset limit, a yellow light will flash and a short tone will sound
- If excessive pressure is not immediately resolved, cycling is paused and alarm sounds continuously
Set Respiratory Rate

Breaths per minute (BPM):

- Dogs: 8 to 14
- Cats: 10 to 14
Inspiratory: Expiratory Ratio

- Inspiratory time is typically 1 to 1.5 seconds in small animals.

- I:E ratio minimally should be 1:2 (e.g., 1:3, 1:4, based on respiratory rate).

- The Hallowell 2000 I:E ratio is preset 1:2
  - Set so positive interpleural pressure minimally interferes with venous return and cardiac output.

- SurgiVet SAV2500 has adjustable I:E ratio
  - Inspiratory time can be set 0.5 to 3 seconds.
Pre-set Volume

- Ensure Volume control is at lowest possible settings
  - Lowest $V_T$ deliverable = 20 mls
Set Tidal Volume

Calculate the Tidal Volume:

15 mL/kg (10-20 mL/kg)

- Guideline: ~ ½ the patient’s lbs. X 10

- GOAL: 35-45 mmHg (40 mmHg)

- Set volume to minimal settings and adjust prn
  - Estimate tidal volume from bellows housing scale during spontaneous respiration
Set Volume

- Begin with Volume control at lowest possible settings
  - Once patient connected, slowly increase volume based on ETCO$_2$
Volume Alarm

Low Breathing System Pressure

- Alarm activated at end of inspiration if <5 cm H₂O PEEP sensed by APST
- **Alarm sounds like a siren/stolen car alarm and will activate due to:
  - Small breath delivered
  - Patient disconnected
  - Oxygen running low
  - Patient breathing against ventilator
Inspiratory Hold (Insp Hold)

- Pauses breathing cycle
- Holds lungs inflated

- Breath holding feature will abort once MWPL set point is exceeded

**Turn off or decrease oxygen flow to minimize pressure changes and possible breath abortion**
Endotracheal tube placement is important!

**Shorten ET tubes to eliminate excessive ‘dead space’**

Correct

Incorrect
Capnography Proper Set Up

Capnogram

PCO₂ = 40

End-tidal PCO₂

PCO₂ = 0
Capnogram Interpretation

![Normal Capnogram Diagram](image)

- **Inspiration**
- **Expiration**
- **Inspired carbon dioxide**
- **End tidal carbon dioxide**

**CO₂ (mmHg)**

**TIME**
Capnogram Interpretation
Capnogram Interpretation

![Capnogram Image]
Capnogram Interpretation
Capnogram Interpretation

Rebreathing

\[ \text{CO}_2 \text{ (mmHG)} \]

TIME
Capnogram Interpretation
Capnogram Interpretation

Hyperventilation

\[ \text{CO}_2 \text{ (mmHg)} \]

\[ 0 \]
Capnogram Interpretation
Capnogram Interpretation

Cuff Leak

\[
\text{CO}_2 \text{ (mmHG)} \quad \text{TIME}
\]

40
0
Capnogram Interpretation

![Capnogram Diagram](image-url)
Capnogram Interpretation
Capnogram Interpretation
Capnogram Interpretation

Cardiogenic Oscillations

\[ CO_2 \text{ (mmHg)} \]

TIME

40

0
Capnogram Interpretation
Capnogram Interpretation

- Watch for small movements of pressure manometer needle!
Ventilator Weaning

Respiratory drive regulated via oxygen & carbon dioxide tension in blood

Two methods:

- ‘Cold turkey’
  - Turn ventilator off
  - Wait 1 minute
  - If no spontaneous breath is observed, turn ventilator on for 1 breath
  - Repeat process until spontaneous respirations return
Ventilator Weaning

- **Gradual method**
  - Turn **Rate** down as low as possible (<6 BPM)
  - Turn **Volume** down as low as possible to avoid inciting alarms
  - Observe bellows for return of spontaneous respirations
  - Once patient has resumed spontaneous respiration, turn ventilator off
Troubleshooting Capnography

**Equipment Considerations**

- Malfunctioning one-way valves
- Inadequate seal at ET tube cuff
- Inadequate oxygen flow rate
- Moisture within sampling line
- Ineffective (old/wet) CO$_2$ absorbent
- Esophageal intubation
- Disconnects
Troubleshooting Capnography

Patient Considerations

- Thoracotomy cases
  - ETCO₂ margin of error
    - ABG result ~ 6 mmHg higher than ETCO₂

- Metabolic derangement
  - Metabolic acidosis cases may have respiratory alkalosis as pH compensation

- GDV / diaphragmatic hernia cases
  - May require smaller Vₜ; increase BPM
Artificial Ventilation Precautions

- Decrease in arterial blood pressure and cardiac output due to:
  - Average airway pressure >10 mmHg (Ventilator induced)
  - Low circulating blood volume (e.g., anemia, blood loss or dehydration)
  - Impaired sympathetic nervous system activity (e.g., anesthesia, local anesthetics, shock)
Artificial Ventilation Precautions

- Positive pressure in trachea and lungs may be transmitted to thoracic cavity resulting in:
  - Impaired venous return
  - Decreased cardiac output
Ventilator Induced Lung Injury (VILI)

- Barotrauma: pressure-induced lung injury
- Volutrauma: volume-induced lung injury
- Biotrauma: due to sepsis, +/- SIRS, etc.
- Atelectotrauma: 2° atelectasis
- Oxygen Toxicity: >12-16(+) hours
- Long-term = pneumonia risk
Know Your Equipment!

- Know how to properly use ventilator \textit{before} an emergency arises
  - Improper hook up or use of equipment can result in lung injury! (e.g., barotrauma, volutrauma)

- **Under no circumstances** should O$_2$ flush on anesthesia machine be used while connected to a patient!
  - Using the flush button during inspiratory phase of breathing cycle can cause severe injury!!!

- **Do not** use alcohol or any other harsh chemical to clean ventilator or bellows
  - Use only a damp cloth
Recommended Reading & Viewing:
www.capnography.com
www.hallowell.com
Anesthesia Ventilators 101
YouTube
Training: SurgiVet SAV25000 (sic) Ventilator