COVID-19 Preparation: Basics of Ventilation and Anesthesia Machine Use in the ICU

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Why are we discussing this?

- Threat of pandemic respiratory illness/failure has resulted in a number of solutions (e.g., ventilator stockpiling, single ventilator to support > 1 patient, & triage)
- Due to the predicted number of ventilated patients with COVID-19 associated lung injury and ARDS, we need to prepare for off-label use of GE anesthesia devices for ICU ventilation
- Anesthesia devices are complex systems an are designed/intended to be fully attended/monitored devices
    - Require a clinician at the device nonstop to ensure the proper use and continuous monitoring of the anesthesia device

Before Using the Device for the First Time:

- Machine will have to be ”checked out” (defer to anesthesia or RT)
- Flush/Purge machine of residual gases
- **Always have backup ambu bag and alternate O2 source available**

Length of Use and Daily Checkout

- Anesthesia devices are NOT intended for long-term ventilation use
- Need to be rebooted/restarted everyday (q24hours) to ensure proper calibration, accuracy, and performance
  - “Please do checkout” general message will appear q24 hours
  - The accuracy of volume delivery will be affected if not checked out q24 hours
- To do:
  - Q24hours: turned GE anesthesia device off/on and perform full check out
  - If performing the checkout during ventilation, place patient on ambu-bag and manually ventilate them while checkout is performed by second provider
- Disclaimer: Aiysis GE ventilators will shut down (stop ventilation) if they run for 49 days consecutively without reboot

Demonstrate Machine Checkout

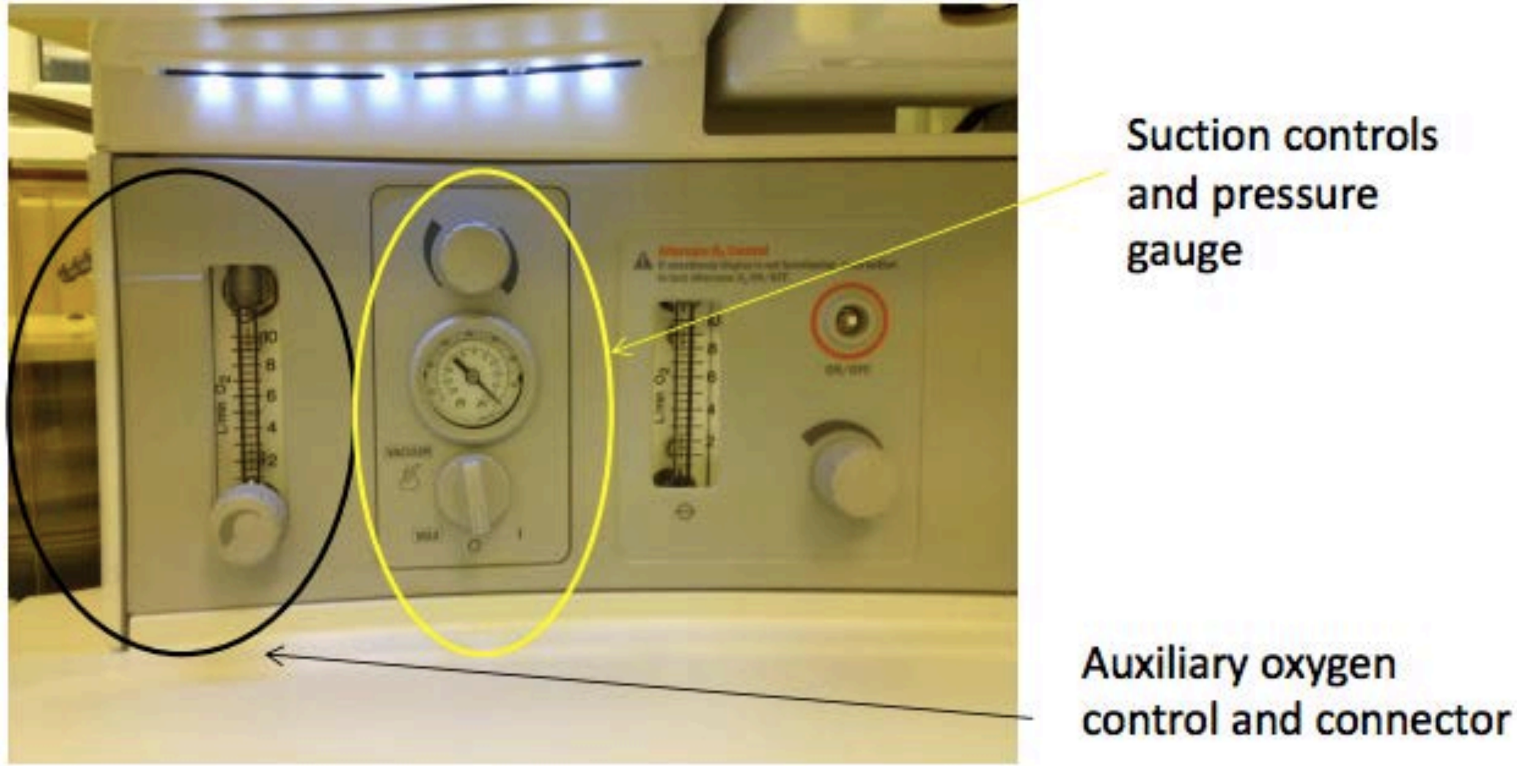
Here is a video of how to perform a machine checkout on a GE Avance CS2 Anesthesia Machine: https://www.youtube.com/watch?v=fUfUItwvwB8. We use GE Aiysis C52 but the steps are essentially the same!

Best advice is to turn the machine on and then follow the prompts on the interface! Super easy and intuitive ☺

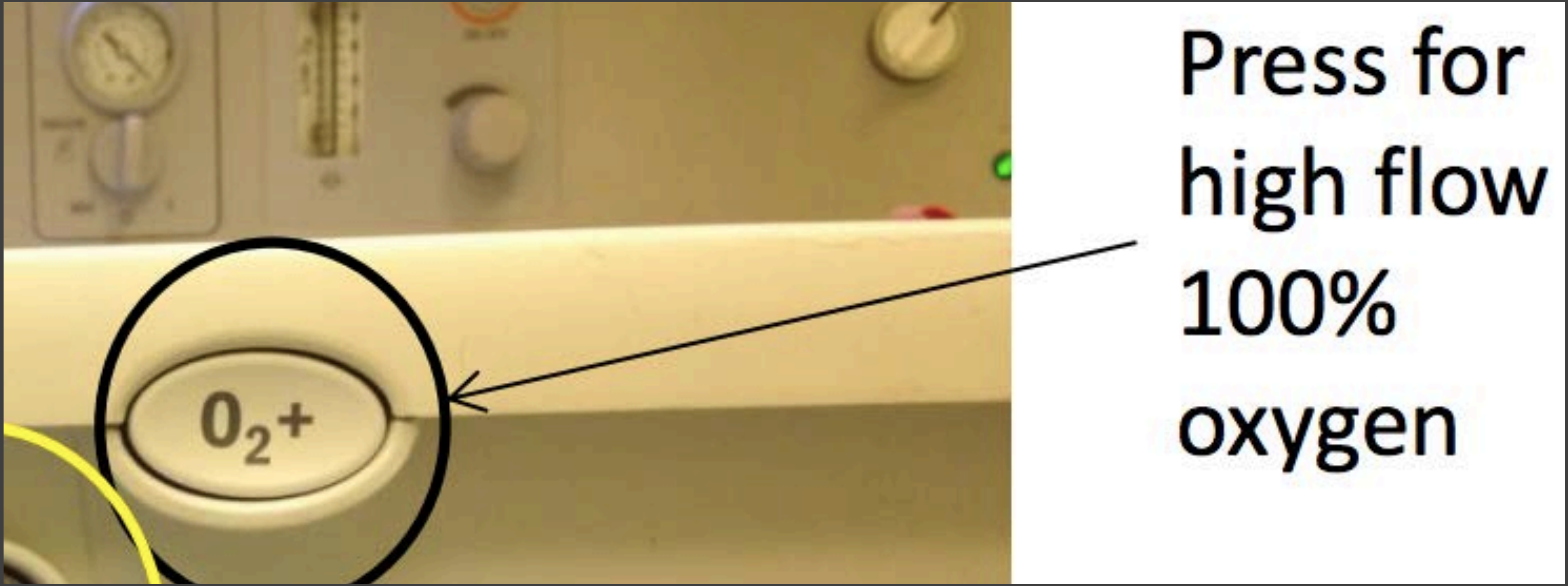
Don’t forget to check for an alternate O2 source (O2 cylinder) and emergency resuscitation equipment (ambu bag)!

The 'On/Off' switch is under the vaporisers on the right.

Auxiliary Oxygen and Suction



- The auxiliary oxygen control is under the display on the left (black circle). This can be used with an ambu-bag if there is a machine failure.
- Suction controls are to the right of the auxiliary oxygen control (yellow circle). Select ‘max’ for high suction. Select ‘1’ for adjustable suction. Adjust using the trim knob above the pressure gauge.



Oxygen Flush

- High flow (70LPM) 100% oxygen (bypasses vaporizer)
- **<u>Can be used to fill bellows but if pushed during inspiration can cause BAROTRAUMA</u>**

Flushing/Purging Machine of Residual Gases

- Before using the machine, flush the whole machine of anesthetic gases (requires the machine to be powered ON)
- Residual anesthetic gases in the circuit to prevent the risk of medication interactions
- Risk of malignant hyperthermia if the patient is susceptible to inhaled anesthetic agents → even a small amount of agent can trigger this risk
- Recommended to disconnect/remove the vaporizers and any other unnecessary connections (e.g., N20) before use of the device

Different Parts of an Anesthesia Ventilator

- Power ON/OFF button
- Valves (expiratory and inspiratory)
- Bag vs. vent switch
- Auxiliary O2 flow meter
- Vaporizers
- O2 tanks
- Fio2 (turn up to 100%)
- Bag arm with bag from circuit
- Gas sampling
- O2 flush button
- Co2 absorber cannister
- Pressure gauges (atmosphere vs. cylinder)
- Bellows/Bellows housing
- Suction hookup, tubing, and cannister
- Monitor
- APL valve (think of this like a PEEP valve)

Helpful Guide to Aisys C52 GE Ventilator: http://etherweb.bwh.harvard.edu/education/PHILIP/AisysCS2ParticipantGuide.pdf

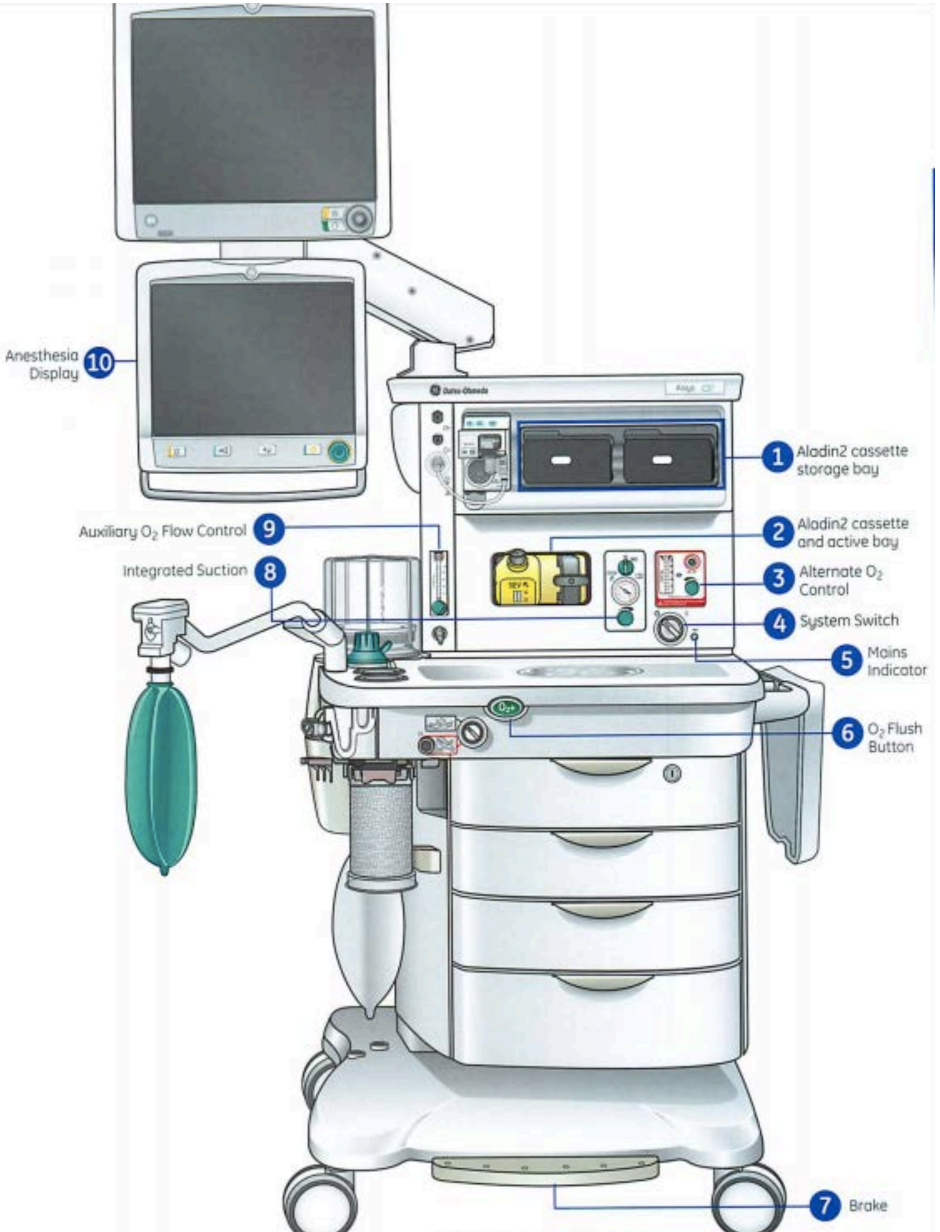


Figure 2.1 Aisys CS² Front View

Front View

1. **Aladin2 Cassette Storage Bay:** Storage bay for Aladin cassettes that are not in use.
2. **Aladin2 Cassette and Active Bay:** The Aladin2 cassette is an electronic vaporizer that controls agent mixing and delivery.
3. **Alternate O2 Control:** The Alternate O_2 control activates automatically in the case of certain failures or errors and delivers O_2 through an independent path to the vaporizers and patient circuit. It can also be activated manually.
4. **System Switch:** Used to turn the system on and off. When the system is turned on, the display will show the power-up screen and the system does a series of automated self-tests.
5. **Mains Indicator:** The mains indicator is lit when AC power is connected.
6. **O_2 Flush Button:** Push the O_2 flush button to deliver a high flow of O_2 to the breathing system.
7. **Brake:** Push down the brake pedal to lock the system in place. Lift up on the brake pedal to release the brake.
8. **Integrated Suction:** The optional integrated suction adjusts the vacuum used to suction fluids from the patient during a case. The switch can be set to max for full vacuum, Off for no vacuum, or On for adjustable vacuum.
9. **Auxiliary O_2 Control:** The optional auxiliary O_2 flowmeter is most often used to deliver oxygen through a nasal cannula or mask.
10. **Anesthesia Display:** The anesthesia display is used throughout the anesthesia delivery process and allows the clinician to interact with the system. The display also provides real-time patient data.

http://etherweb.bwh.harvard.edu/education/PHILIP/AisysCS2ParticipantGuide.pdf

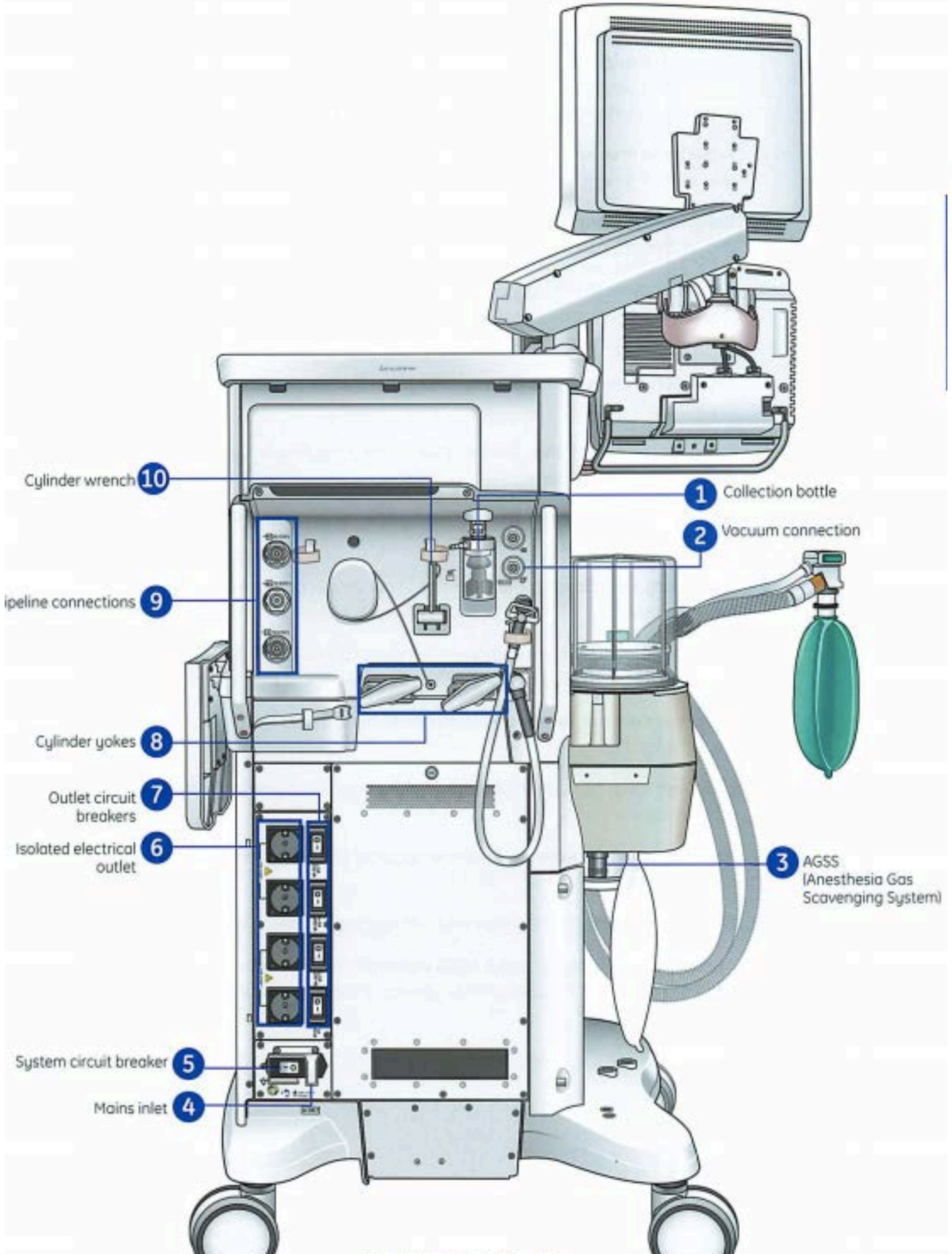


Figure 2.2 Aisys CS² Rear View

Rear View

1. **Collection Bottle:** The collection bottle prevents fluids from entering the optional suction regulator.
2. **Vacuum Connection:** Connect the vacuum connection to the source vacuum supply.
3. **AGSS (Anesthesia Gas Scavenging System):** The scavenging system is designed to safely remove excess gas from the anesthesia machine.
4. **Mains Inlet**: AC power is connected to the system through the mains inlet.
5. **System Circuit Breaker:** This is the main circuit breaker. It should not be mistaken for an on/off switch. Accidentally pressing this switch will cause the system to be powered by its reserve battery instead of electricity from the wall outlet.
6. **Isolated Electrical Outlet:** A place to plug in low power accessories that are used in conjunction with the anesthesia machine.

   Note! *The electrical outlets are for low power only! Do not use these outlets for equipment such as blanket warmers and operating room beds.*

7. **Outlet Circuit Breaker:** An automatically operated electrical switch designed to protect the system from damage caused by overload. Unlike a fuse, which operates once and then must be replaced, a circuit breaker can be reset to resume normal operation.
8. **Cylinder Yokes:** Gas cylinders are mounted on the cylinder yoke.
9. **Pipeline Connections:** Hoses are connected between the pipeline inlets and the gas outlets in the hospital.
10. **Cylinder Wrench:** The cylinder wrench is used to open and close the gas cylinders.

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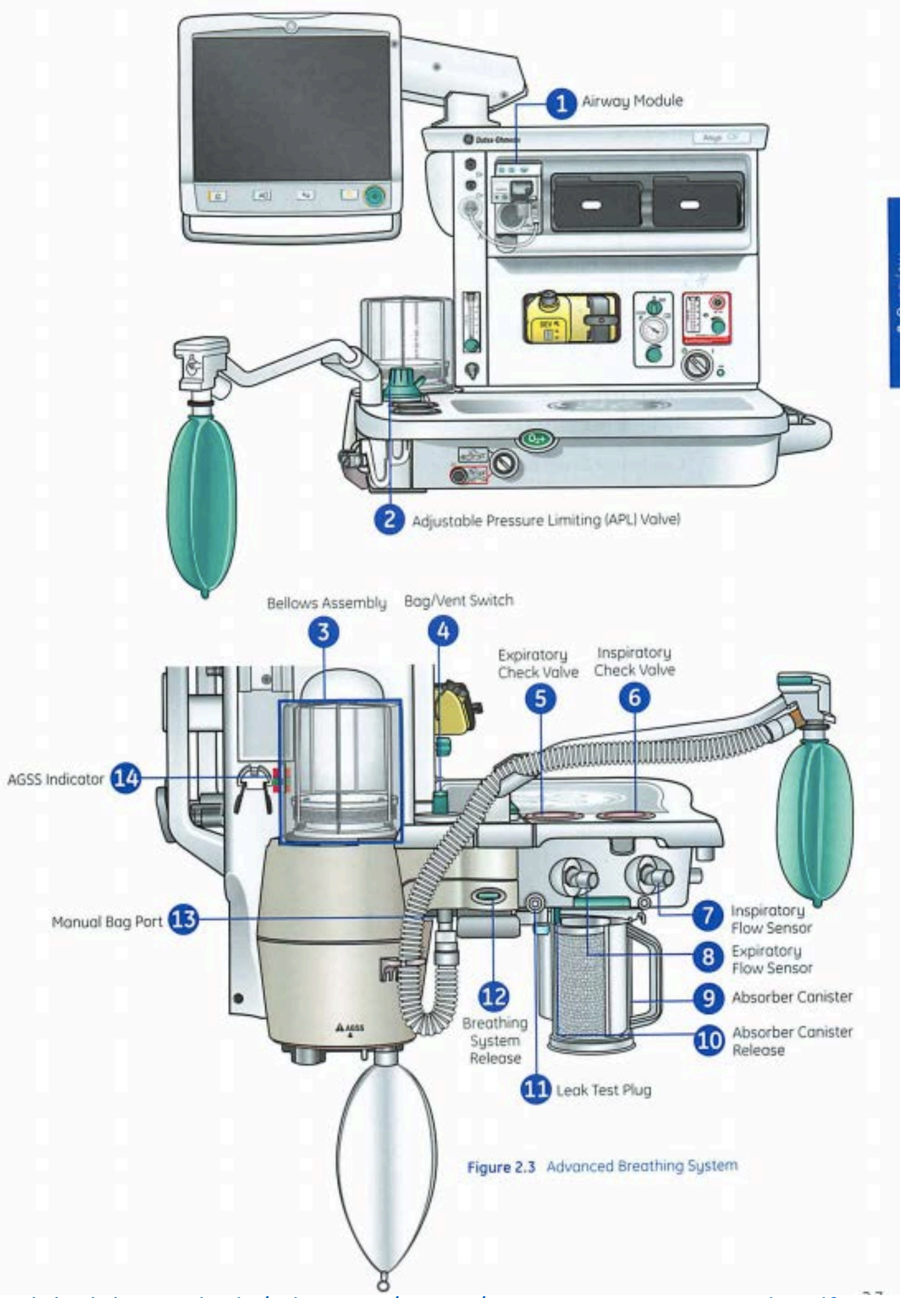

Figure 2.3 Advanced Breathing System

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Advanced Breathing System (ABS) Components

1. **Airway Module (optional):** The airway module measures and monitors gases delivered to the patient. Depending on the configuration, this component may include sensors for measuring carbon dioxide, nitrous oxide, anesthetic agents and oxygen.
2. **Adjustable Pressure Limiting (APL) Valve:** During manual ventilation, the APL Valve allows you to change the pressure limit from minimum to 70 cmH_2O.
3. **Bellows Assembly:** During mechanical ventilation, the gases that are to be delivered to the patient are contained within the bellows assembly.
4. **Bag/Vent Switch:** The Bag/Vent switch selects between manual ventilation (bag) and mechanical ventilation (vent). When the switch is changed from bag to vent mode, the ventilator is automatically switched on.
5. **Expiratory Check Valve:** The expiratory check valve opens during expiration and closes at the start of inspiration.
6. **Inspiratory Check Valve:** The inspiratory check valve opens during inspiration and closes at the start of expiration.
7. **Inspiratory Flow Sensor:** The inspiratory flow sensor determines the volume of gas flowing to the patient.
8. **Expiratory Flow Sensor:** The expiratory flow sensor determines the volume of gas flowing from the patient.
9. **Absorber Canister:** This component removes carbon dioxide from the patient's exhaled breath. These scrubbed gases can then be sent back to the patient.
10. **Absorber Canister Release:** Push the absorber canister release to remove the canister from the holder.
11. **Leak Test Plug:** Occlude the breathing circuit using the leak test plug as part of the preoperative tests.
12. **Breathing System Release:** Push the absorber canister release to remove the breathing system.
13. **Manual Bag Port:** The bag hose and rebreathing bag attach to the manual bag port.
14. **AGSS Indicator (only on some AGSS versions):** With an active Anesthesia Gas Scavenging System (AGSS) that includes a flow indicator, the ball on the indicator should rise to the green zone.

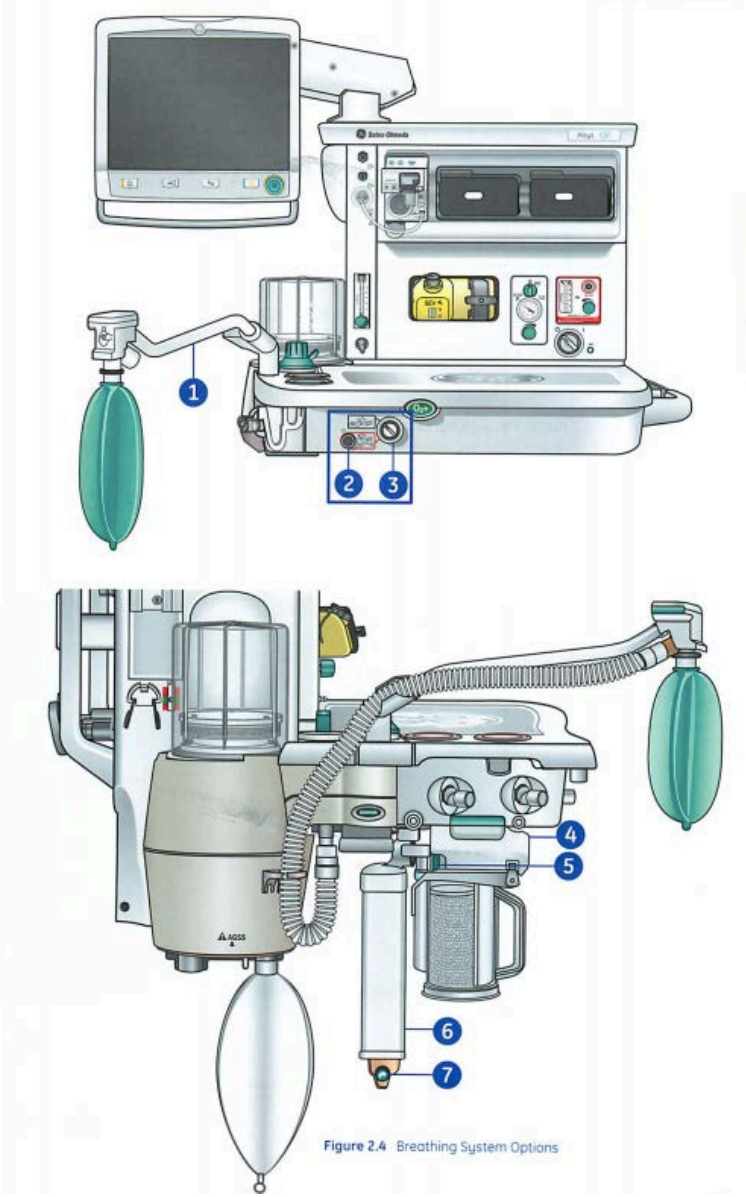


Figure 2.4 Breathing System Options

Breathing System Options

1. **Bag Support Arm:** Use the optional bag support arm to hold the breathing circuit bag.
2. **ACGO Port:** Fresh gas flows through the ACGO port when the ACGO switch is set to the ACGO position.
3. **Auxiliary Common Gas Outlet (ACGO) Switch:** Use the optional Auxiliary Common Gas Outlet (ACGO) switch to direct the fresh gas flow through the ACGO port on the front of the system to a manual breathing circuit.
4. **EZchange Canister Mode (CO_2 bypass):** Use the optional EZchange canister mode for continued ventilation of the patient while changing the absorber canister.
5. **EZchange Canister Release:** Push the EZchange canister release to unlock the canister cradle.
6. **Condenser**: Use the optional condenser to remove water in the system that is produced from the reaction of CO_2 gas with the absorbent.
7. **Condenser Drain Button:** Place a container under the reservoir and push the drain button to empty any water in the condenser.

http://etherweb.bwh.harvard.edu/education/PHILIP/AisysCS2ParticipantGuide.pdf

Demonstrate: How to Hook Up a Circuit

CO2 Absorber

- Need to eliminate CO_2 in exhaled gas to prevent hypercapnia
- Soda lime is a key element in a rebreathing circuit and inappropriate use can be harmful or even lethal
- Failure to change the CO_2 absorber when depleted will result in an increased inspired CO_2 ($FiCO_2$)→causes rebreathing, excess CO_2, and insufficient oxygenation
- Lack of moisture increases sodalime exhaustion
- **When to change sodasorb CO_2 cannister:**
    - **INCREASED $FiCO_2$ (detected by capnography) → most reliable**
    - Color change (White Violet): going by color can be deceiving because fully exhausted violet cannister will begin to turn back to white once ALL the CO_2 absorption granules are depleted
    - Lack of heat
    - Clinical signs
    - Harness of granules
    - Time in function

Detecting Amsorb Exhaustion

- **Most reliable method: measuring inspired CO2 (FiCO2)**
  - FiCO2 > 5 (change cannister! Machine alarm will be set to alarm for high FiCO2 until you change cannister)
- Indicator color change (not as reliable)

Measuring inspired CO_2 is the **most reliable method** to detect absorbent exhaustion. This can be done with a **capnograph**. A typical waveform obtained during CO_2 reinspiration caused by soda lime exhaustion is illustrated in Figure 1. During inspiration, **the patient breathes CO_2: the curve does not return to 0 during inspiration.** The shape of the trace is normal, and the end-tidal CO_2 value is increased.

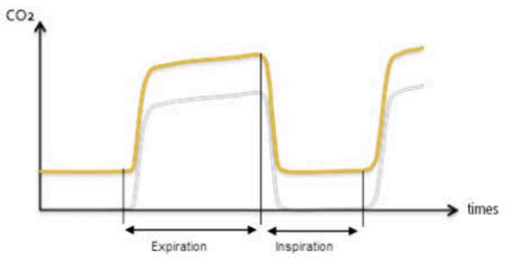


Figure 1: Typical capnograph waveform obtained when soda lime is exhausted (yellow), compared to a normal waveform (grey). During inspiration, the curve does not return to 0, but the shape of the waveform is normal. End-tidal CO_2 value is increased.

Indicator color change

When CO_2 reacts with soda lime, heat and water are formed, and pH changes. The latter causes the **indicator contained in soda lime to change color (typically from white to pink), indicating that the absorbent is near the point of exhaustion.**

Absorbent should be changed when 2/3 of the canister has changed color. Keep in mind that the color may **revert back to its pre-exhaustion color** when not in use. Upon reuse, the indicator color will rapidly return to it's exhausted state. Therefore, a rested canister can give a false sense of security. For this reason, **inspection of the absorbent color should be made during or just after anesthesia**.

Additionally, if the absorbent is not packed properly in the canister, **channeling** can occur: the airflow passes through a channel in the soda lime, exposing only a small part of the absorbent to CO_2. As absorbent along the channel becomes exhausted quickly, the patient rebreathes CO_2. The rest of the soda lime remains white, giving a **false sense of security**. Figure 2 illustrates those patterns of absorption.

Therefore, indicator color change is useful but is not reliable.

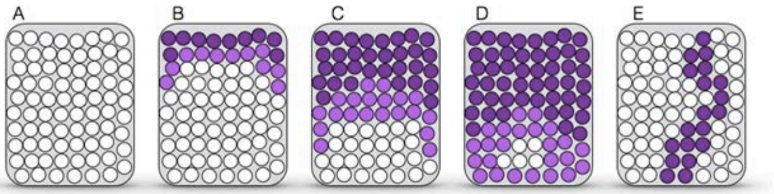


Figure 2: Pattern of CO_2 absorption in the canister. Purple circles represent exhausted soda lime; white circles represent fresh soda lime.

Demonstrate How to Change a CO2 Cannister

The granules are pale when unused. Their colour changes due to a chemical change when CO_2 is absorbed.

The canister can be removed and replaced very easily (see photo on right). This should be avoided during a case, as the new canister will contain air and dilution of volatile agent will occur when it is inserted.

Ventilation Alarms

- Due to the audio alert levels (volume) may not be adequate for the ICU environment and do not alerts via the hospital nurse call alarm system
- **Always have backup ambu with alternate oxygen source (O2 cylinder) when trying to troubleshoot any alarm! Also know how to turn up FiO2 up to 100%!**
- **Always enable all alarms!**
- **Turning off machine (for checkout) RESETS every alarm to default-->WILL NEED TO RECONFIGURE ALARM SETTINGS AFTER EACH CHECKOUT**
- High- and Low-pressure alarms:
  - High airway pressure alarms: worsening pulmonary compliance, increase in Vt, obstruction in breathing circuit
  - Low pressure alarms: improvement in compliance, decrease in Vt, or leak
  - Other alarms: High PEEP, High PIP, negative pressure, low oxygen supply pressure
- **Disconnect alarms are the most important and must always be activated and are caused by the following…**
  - Low Peak inspiratory pressures
  - Low exhaled Vt
  - Low exhaled EtCO2
- **Power supply problems or loss of power: backup battery for 30-45 minutes and then will automatically turn off**
- Large leaks→ patient unable to obtain enough oxygenation or allow for CO2 clearance
  - How to check for leaks: circuit check, bellows do not reach the top of the housing at the end of the expiratory cycle.

High vs. Low Pressure Alarms

- Never turn off the alarms!
- Alarm silence button pauses alarm for 2mins
- Asses the patient NOT the alarm!
- Low Pressure: circuit leaks, airway leaks, chest tube leaks, patient disconnected
- High Pressure: coughing, biting tube, fighting ventilator, secretions.mucus in airway, reduced lung compliance, water in the circuit, kink

VENTILATOR ALARMS

ALARM	DEFINITION	POTENTIAL CAUSE
1. High pressure	•Pressure required to ventilate exceeds preset pressure	Pneumothorax, excessive secretions, decreased lung compliance.
2.Low pressure	•Resistance to inspiratory flow is less than preset pressure.	Disconnected from ventilator, break in circuit.
3.Low exhaled volume	•Exhaled tidal volume drops below preset amount.	Leak in system, increased airway resistance, decreased lung compliance
4.Rate /apnea	•Respiratory rate drops below preset level. Apnea period exceeds set time	Client fatigue, decreased R.R due to medication.
5. FIO2	•Indicates FIO2 drift from preset range.	Change in level of consciousness, disconnected from O2 source, break in circuit.

Ventilator Alarms (Continued)

Upper airway pressure alarm

- Coughing
- Endotracheal/tracheostomy tube obstruction
- Kinking of endotracheal tube
- Biting of endotracheal tube
- Increased airway secretions
- Clogging of HME
- Excessive condensation ("raining out") into the ventilator circuit
- Downward migration of endotracheal tube into a mainstem bronchus
- Herniation of the endotracheal tube cuff
- Bronchospasm
- 'Clashing' with the ventilator
- Low lung compliance (pulmonary edema, pneumothorax, collapse of a lobe or lung, consolidation)
- Inspiratory/expiratory valve

Lower airway pressure alarm

- Disconnection
- Upward migration of ET
- Circuit leak at connection points
  - HME
  - Humidifier
  - Water trap
  - Closed suction catheter
  - Temperature sensors
  - In-line nebulizers
  - Exhalation valve
- ET Cuff
  - Inadequately inflated ET cuff
  - ET cuff deliberately under-inflated to provide a "minimal leak" (see p...)
- Pilot bulb leakage
- Bronchopleural fistula with chest drain in situ

Alarm Priorities: Look at the Color

Alarm Priorities

Alarms may be high priority, medium priority, or low. Alarm priority is indicated by the color of the alarm message and the audio sequence.

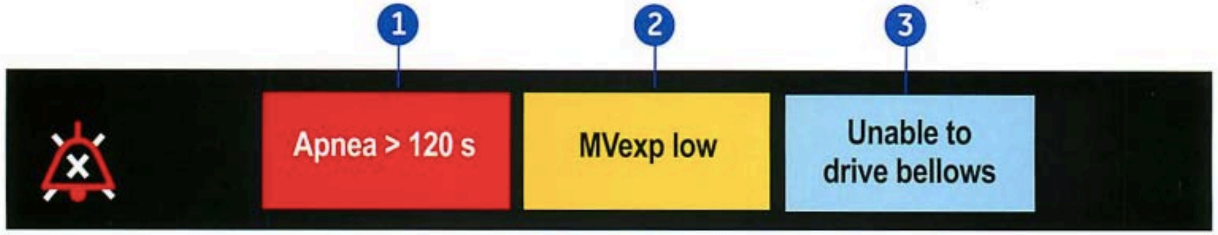


Figure 6.14 Priority Alarm Examples

1. **High-priority alarm** messages appear in white text on a red background.
2. **Medium-priority alarm** messages appear in black text on a yellow background.
3. **Low-priority alarms** appear in black text on a blue background.

Pausing Alarms

Figure 6.15 Audio Pause Key

Selecting ***Audio Pause*** for an active alarm stops the audible tone for 120 seconds. The alarm message shows in the alarm message field. Selecting ***Audio Pause*** when no medium or high priority alarms are active prevents the audible alarm tones (audio off) for 90 seconds.

Cancelling Audio Pause

Selecting and holding ***Audio Pause*** for 2 seconds will cancel the audio pause function.

De-escalating Alarms

Some device related alarms, such as ***No insp flow*** sensor will de-escalate priority when the alarm is acknowledged by selecting ***Audio Pause***. The alarm message shows at the low-priority alarm level until the alarm condition is resolved and the alarm is cleared. If that alarm reoccurs after it has been resolved, the alarm occurs at its standard priority level.

Setting Alarm Limits: Enable all Alarms & Turning Machine OFF Resets ALL Alarms!

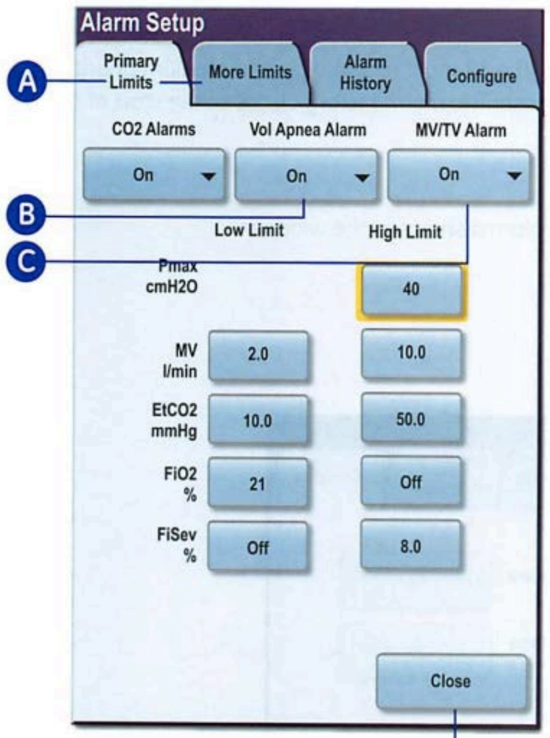


Figure 6.16
Alarm Setup - Primary Limits Tab

Home Key

A. Setting Alarm Limits

1. Select ***Alarm Setup*** from the right side of the display.
2. From the ***Primary Limits*** and ***More Limits tabs***, select the alarm limit and make the change.
3. Push the ***Home*** key, touch the waveform area of the display, or select ***Close*** to close the menu.

B. Setting Volume Apnea Alarm

Note! *The Volume Apnea Alarm setting may not be available if the system has been configured to disable this feature.*

Use the Vol Apnea Alarm setting to turn off the volume apnea alarm during manual ventilation. The volume apnea alarm remains off until the Bag/Vent switch is set to Vent or Vol Apnea Alarm is set to ***On***.

1. Select ***Alarm Setup.***
2. To turn the volume apnea alarms off, select ***Vol Apnea Alarm*** to ***Off.***
3. ***Volume Apnea Off*** shows in the general message field.
   - If mechanical ventilation is started, the volume apnea alarms are active
   - If manual ventilation is restarted, a pop-up confirmation window appears to resume the Off setting
4. To turn the volume apnea alarms on, set ***Vol Apnea Alarm*** to ***On***.
5. Select ***Close***.

C. Setting MV/TV Alarms

Use the MV/TV Alarms setting to turn off the MV and TV alarms.

1. Select ***Alarm Setup***.
2. To turn the volume alarms off, set ***MV/TV Alarms*** to ***Off***.
   - ***MV/TV Alarms Off*** appears in the general message field
   - The volume alarm limits waveform numerics shows dashes during a case
3. To turn the volume alarms on, set ***MV/TV Alarms*** to ***On***.
4. Select ***Close***.

Note! *Settings made during manual ventilation are not retained when mechanical ventilation starts. Settings made during mechanical ventilation are retained when manual ventilation starts.*

Use Environment/Transport

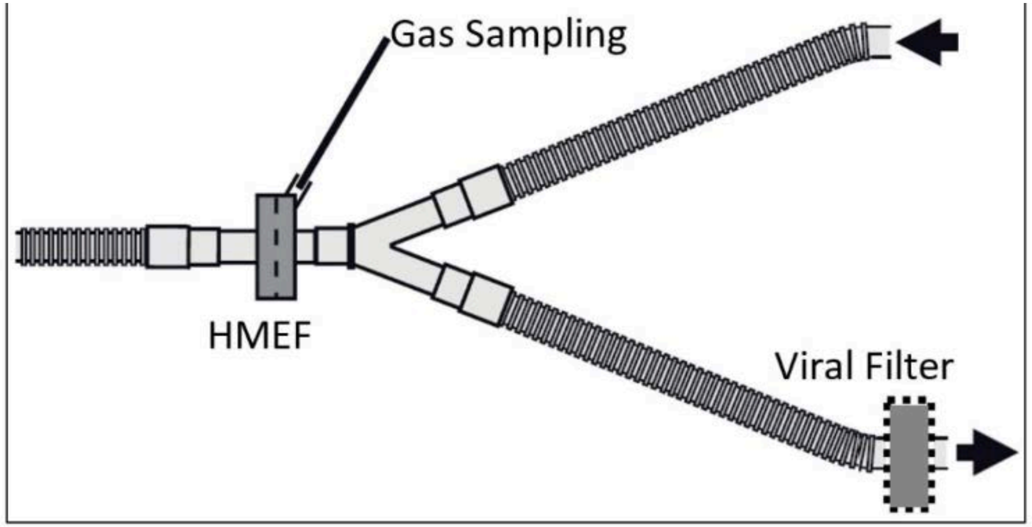
- Anesthesia devices are NOT intended or designed to function while moving
- Not to be used during transport
- You can unplug device but battery backup if fully charged will only last 30-40 minutes

Reprocessing and Cross-Contamination

- **Always place Heat-Moisture Exchange Filter (HMEF) at the patient's Y-piece**
- Place a viral/bacterial filter on the expiratory limb at the connection to the anesthesia machine
- If filter is only used, reduce fresh gas flow to 1-2L/min to preserve humidity
- Follow filter guidelines for replacement timeline/frequency (q24 hours → replace with machine check to keep it consistent!)
- Discard breathing circuits after each patient
- https://www.apsf.org/faq-on-anesthesia-machine-use-protection-and-decontamination-during-the-covid-19-pandemic/#gas

Protect the Anesthesia Machine! Place HMEF at Y-Piece!

- Heat and moisture exchange filters (HMEFs) preserve airway humidity and are designed so that sampled gas is filtered before it enters the gas analyzer
- Aisys CS2 Software VII models return sample gas to Patient Circuit



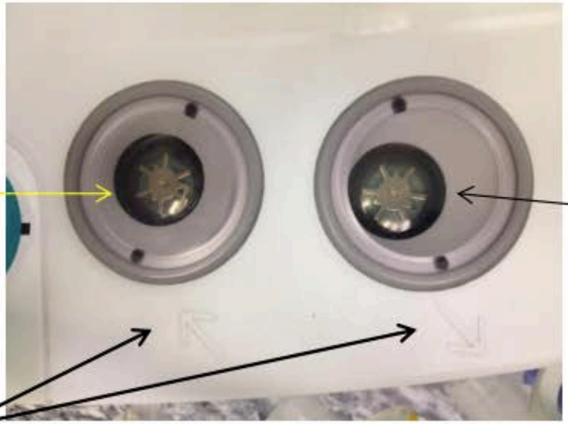
Preferred Filter Configuration

VFE > 99.99% for each filter. Gas sampling on machine side of filter. (Courtesy Draeger Medical)

Circle System One-Way Valves

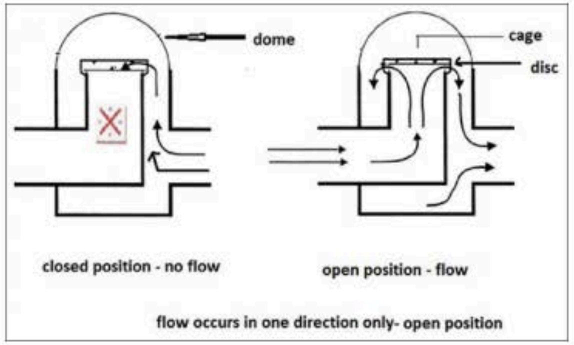
- These valves are simple discs, which rise and fall depending on the direction of gas flow

Expiratory valve:
Opens on expiration and closes with inspiration



Inspiratory valve
(opens on inspiration and closes with expiration)

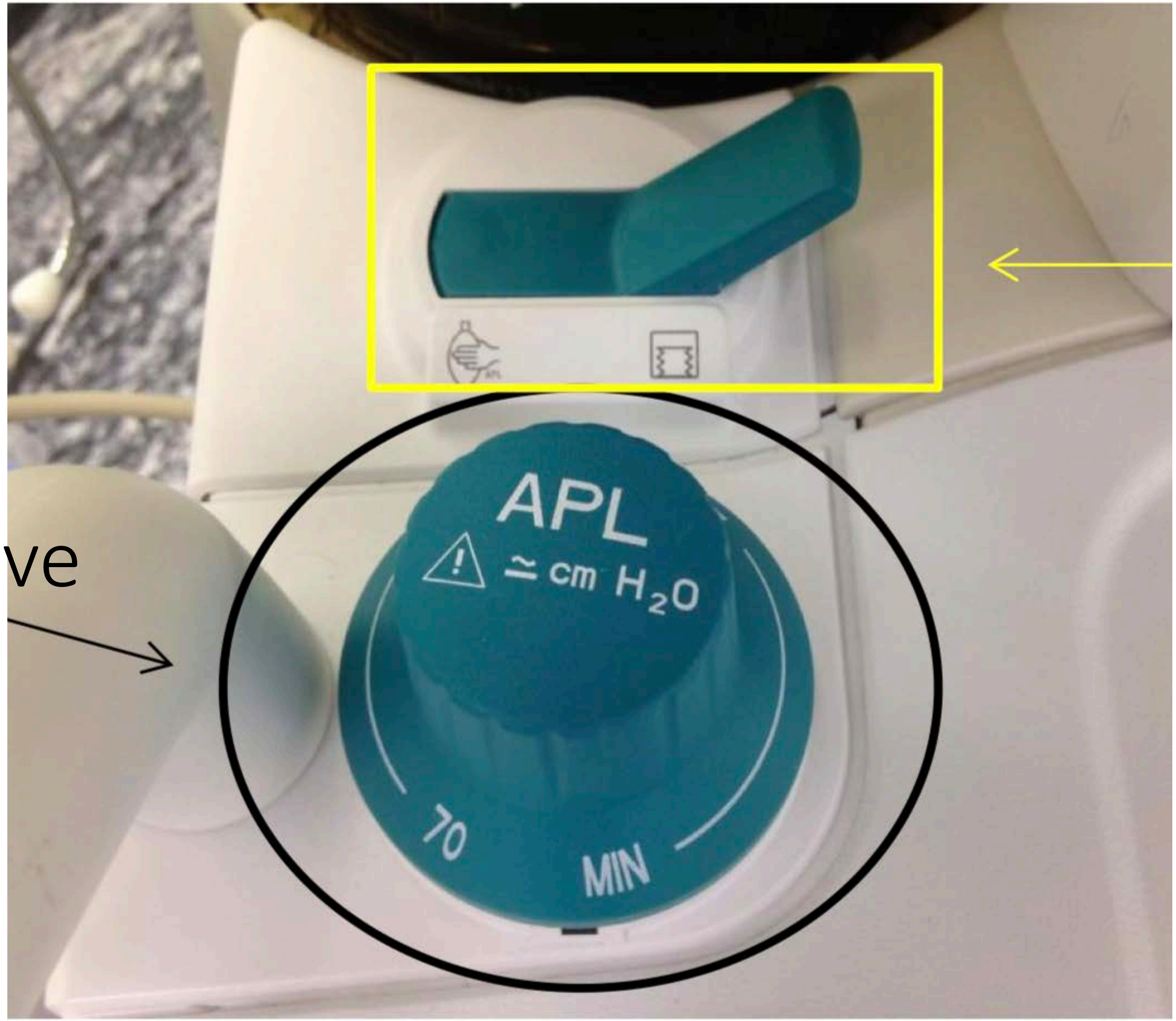
Flow direction arrows



Bag to Vent (BTV)

- Anesthesia devices are not automatically configured to begin mechanical ventilation when a case is started
- ”Bag mode” position: device is not providing any ventilation support to the patient. The gas is flowing; however, the clinician must manually provide ventilation using the equipped bag
  - APL valve (adjustable pressure limiting knob) determines the amount of pressure the patient is receiving
    - Too low may result in no flow delivered to the patient
    - Too high APL setting can result in barotrauma
- Mechanical ventilation begins by moving the switch to the Vent position
- Device bellows provide a visual indicator of ventilation status. If the bellows are not rising and falling, there is no ventilation being provided.

APL Valve



Bag to Vent Switch

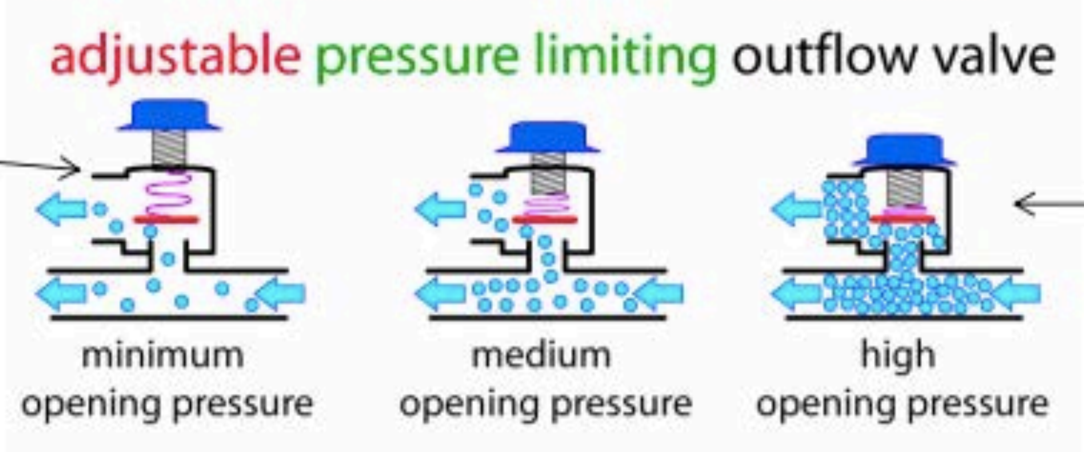
Selecting a Ventilation Mode

- Push the ventilation mode switch to the right to begin positive pressure ventilation with default parameters
- Push the switch to the left to allow spontaneous ventilation or manual positive pressure ventilation (PPV) using the reservoir bag
- Adjust the APL valve to obtain satisfactory pressure for manual PPV

APL valve: rotate clockwise to increase circuit pressure (max $70cmH_2O$)

Ventilator selector switch (in ventilator 'on' position) The APL valve is active only when the switch is in the 'reservoir bag' position (i.e. to the left)

Valve fully open (anticlockwise rotation)



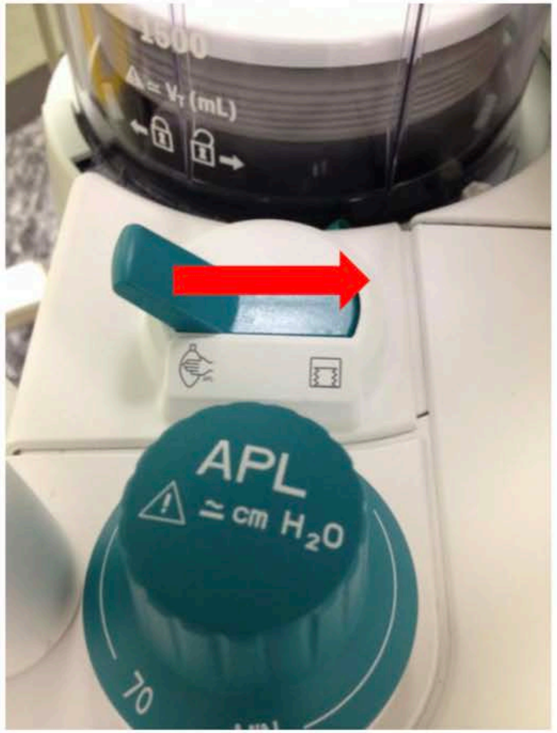
Valve closed (rotated clockwise)

1. Set the ventilator selector switch to bag or ventilator mode.

2. Check APL valve setting if in bag mode. Set at zero for spontaneous breathing or adjust circuit pressure to allow bag ventilation

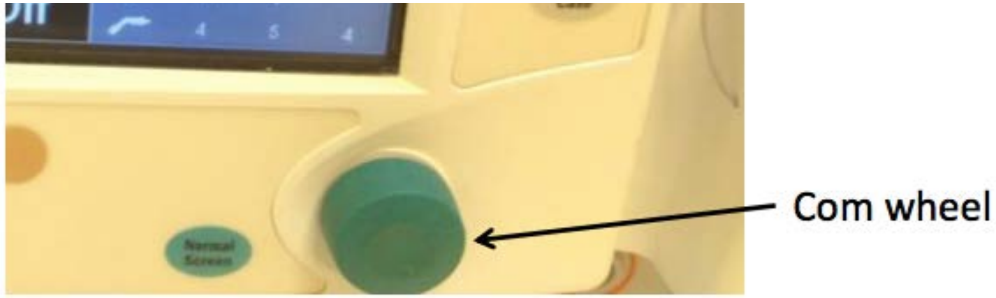
Ventilator mode

Flip bag/vent selector to vent position (red arrow) to begin machine ventilation

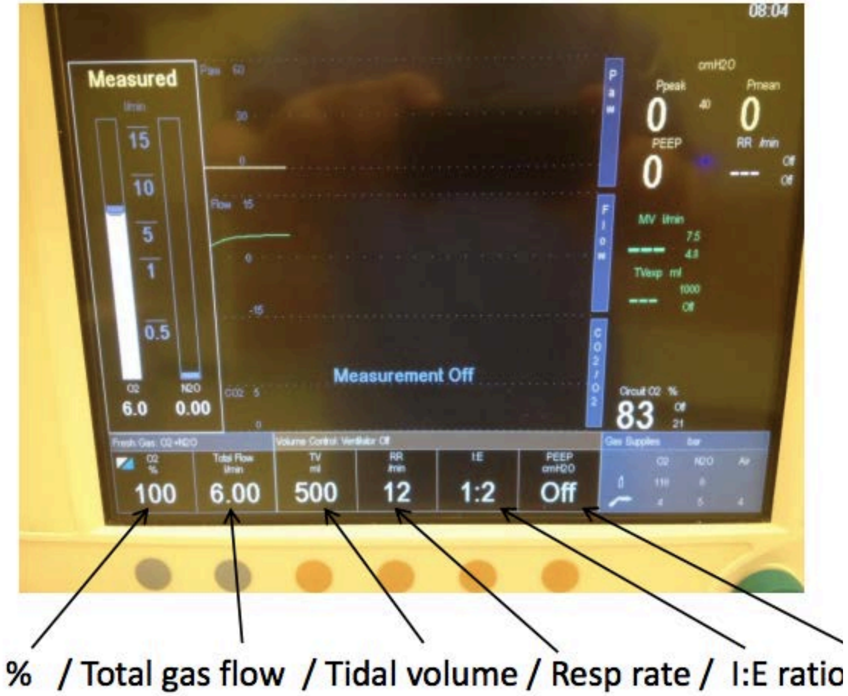


- The machine defaults to pressure control ventilation-volume guarantee (tidal volume 500ml, rate 12, I:E=1:2 and PEEP off).
- Adjust settings with the touch screen and com wheel
- To select an alternative ventilation mode, touch mode button and select from the menu

Default Gas Flows and Ventilator Settings



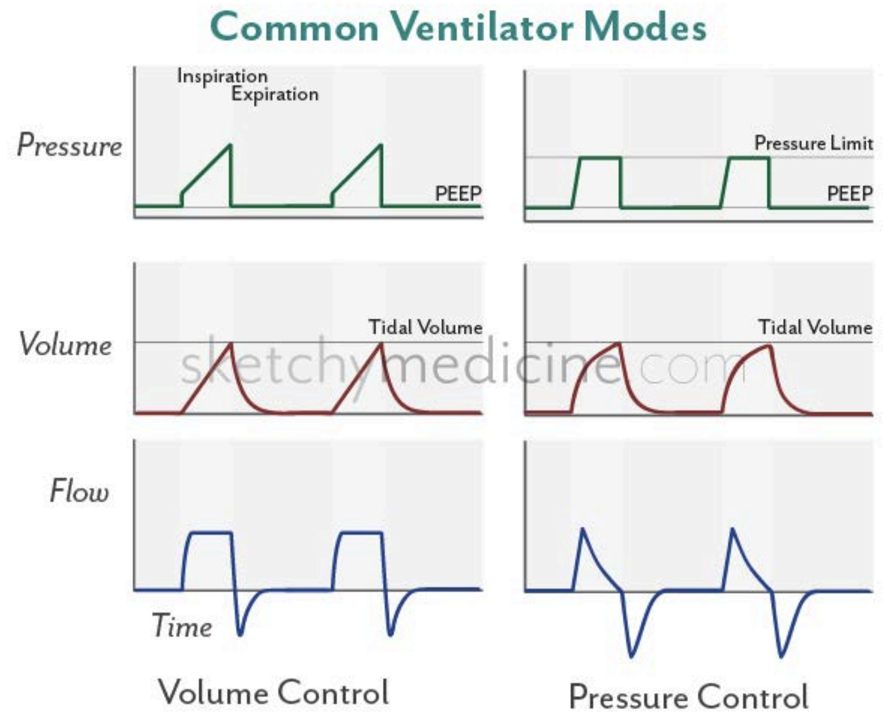
Menu items are selected with the 'Com wheel' (command wheel). Rotate the wheel clockwise or anticlockwise to highlight menu items, then press in firmly to confirm the selection.



Ventilator Basics

Advantages and disadvantages of pressure-controlled and volume-controlled ventilation

	Pressure-controlled ventilation	Volume-controlled ventilation
Advantages	• Reduction of peak pressure and of risk of barotrauma • Improved gas exchange due to decelerating flow • More homogeneousventilation in cases of distribution disorders • Compensates for leaks	• Maintains constant tidal volume • Precise control of partial pressure of carbon dioxide in arterial blood ($PaCO_2$)
Disadvantages	• Hypoventilation secondary to changes in lung compliance and resistance	• Potential for high airway pressures and acute lung injury • Inability to compensate for leaks



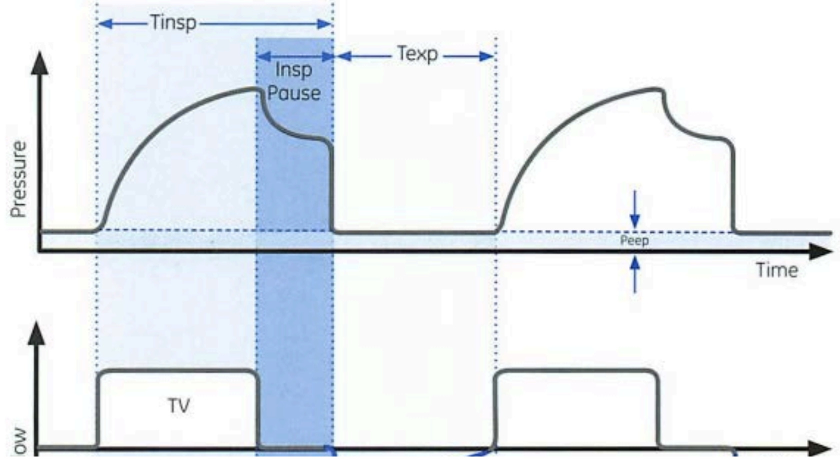
PCV vs. VCV

Volume Control Mode (VCV)

Volume control ventilation supplies a set tidal volume. The ventilator calculates a flow based on the set tidal volume and the length of the inspiratory time to deliver that tidal volume. It then adjusts that output by measuring delivered volumes at the flow sensors. Since the ventilator adjusts output, it can compensate for breathing system compliance, fresh gas flow, and moderate breathing system leaks. A typical volume-control pressure waveform increases throughout the entire inspiratory period, and rapidly decreases at the start of expiration. An inspiratory pause is available to improve gas distribution.

VCV mode settings:

- TV
- RR
- I:E
- Tpause
- PEEP
- Pmax

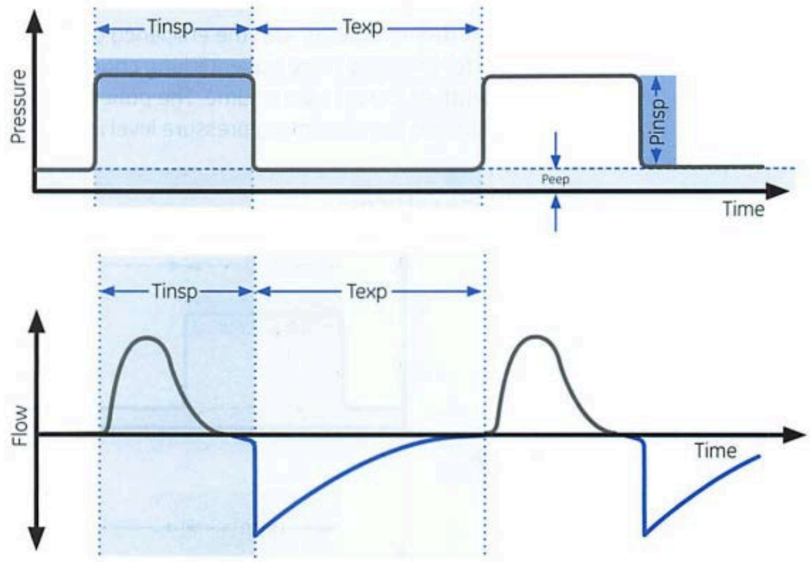


Pressure Control Mode (PCV)

(PCV) Pressure control ventilation supplies a constant set pressure during inspiration. The ventilator calculates the inspiratory time from the frequency and I:E ratio settings. A high initial flow pressurizes the circuit to the set inspiratory pressure. The flow then decreases to maintain the set pressure (Pinsp). Pressure sensors in the ventilator measure patient airway pressure. The ventilator automatically adjusts the flow to maintain the set inspiratory pressure.

PCV mode settings:

- Pinsp
- RR
- I:E
- PEEP
- Pmax
- Rise Rate



Synchronized Intermittent Mandatory Ventilation – Pressure Control Ventilation Mode (SIMV-PCV)

Synchronized intermittent ventilation with pressure control ventilation (SIMV PCV) delivers a relatively slow breathing rate with pressure controlled breathing. This mode combines mandatory breaths with spontaneous breath support. If a trigger event occurs within the synchronized window, a new pressure controlled breath is initiated. If a trigger event occurs elsewhere during the expiratory phase, a support for a spontaneous breath is provided with pressure support added as set by the clinician.

SIMV PCV mode settings:

- Pinsp
- RR
- Tinsp
- Psupport
- PEEP
- Pmax
- Trig Window
- Flow Trigger
- End of Breath
- Rise Rate
- Exit Backup

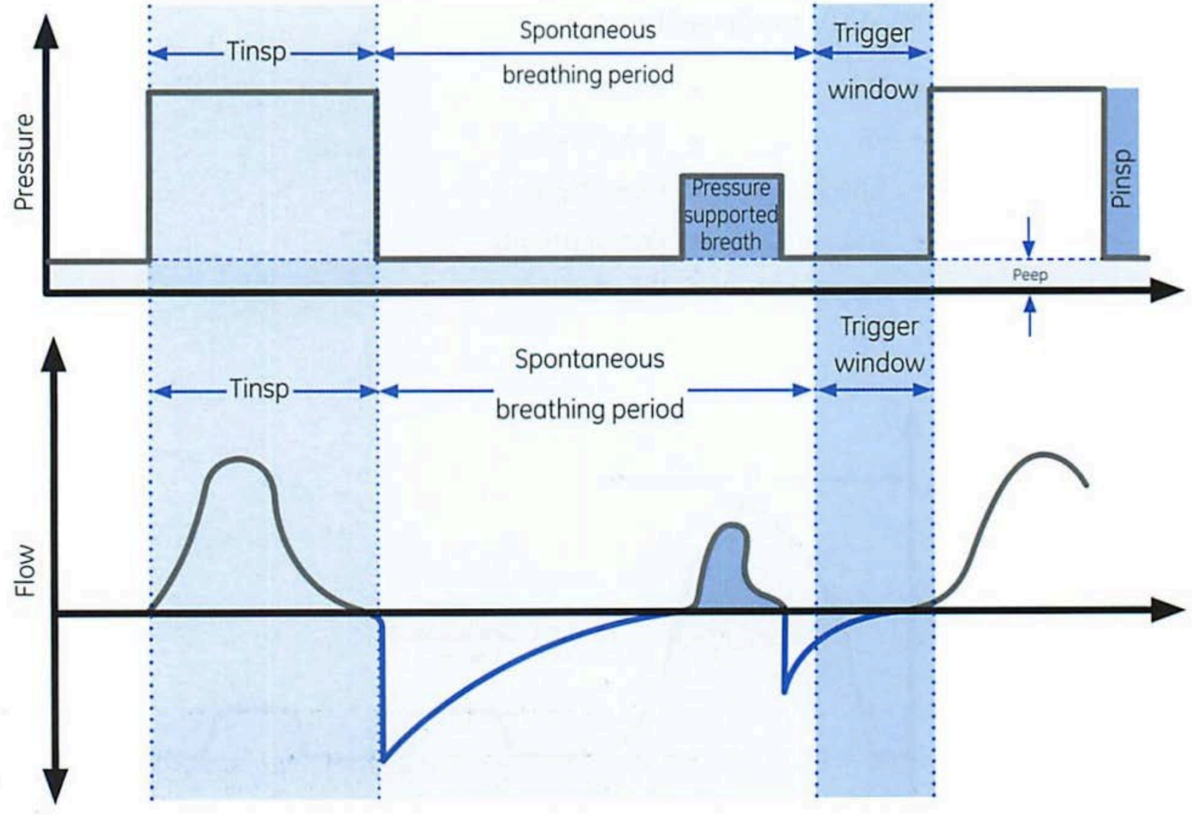


Figure 7.5 Example of SIMV-PCV Waveforms

One Ventilator to Ventilate More than One Patient?

PCV > VCV with Multi-Patient Single Ventilator

- Review of how we normally choose between VCV vs. PCV:
  - VCV: Advantage is delivery of a guaranteed tidal volume (disadvantage is lack of control over peak pressure).
  - PCV: Advantage is guaranteed limitation of the peak pressure (disadvantage is lack of control over tidal volume).
- Once we start splitting a ventilator between multiple patients, this debate largely evaporates. Using a volume-cycled mode has numerous, major disadvantages:
  - Worst of both worlds: No control over the Vt of any patient and their maximal airway pressure.
  - Introduce the possibility of deleterious interactions between patients. *For example, let's suppose Patient A's endotracheal tube gets kinked. This will cause Patient B to receive dangerously large tidal volumes!*
  - Patients sharing the ventilator must have similar size, similar FiO2 and similar PEEP requirements.
- Using a pressure-cycled mode solves these problems:
  - Retain control over the maximal airway pressure and the driving pressure. We cannot deliver a guarantee Vt to any patient, but that is no different from having any patient on PCV. Ability to control and limit the driving pressure may allow this strategy to be reasonably lung-protective.1
  - Deleterious interactions between patients are avoided using a pressure-cycled mode. *For example, if Patient A's endotracheal tube gets kinked in a pressure-cycled mode, then Patient A will receive a reduced tidal volume. However, this will have no impact on Patient B.*
  - Patients sharing the ventilator don't have to have a similar size. Larger patients will tend to have a greater absolute compliance, so they will receive larger breaths.

Basic Setup to Split a Single Ventilator

- First off, watch this video to get an idea:
- https://www.youtube.com/watch?v=uClq978oohY&feature=youtu.be&fbclid=IwAR1pF4Hx_kAA_AJngrXf73rJu1687EZcH2TJYFWz-nPDpjb7FlSP0p7GBG4&fbclid=IwAR3mZwpTK_Uf8IEgHg6A_zoVwYCHrMlo3FEZz5fV1fJ6qXXgHkUvVR-HoWQ
- https://www.youtube.com/watch?time_continue=99&v=NER2h9STy7Q&feature=emb_title
- https://emcrit.org/pulmcrit/split-ventilators/
- https://jamanetwork.com/journals/jama/fullarticle/2763485

Basic Setup to Split a Single Ventilator

- Multiple patients (2-4, possibly 6) attached to a single ventilator. The patients don't need to be the same size, but ideally, they should have roughly similar severity of lung injury (e.g. similar PEEP and FiO_2 requirements)
- PCV with a high PEEP (noting that patients with COVID-19 seem to be highly PEEP-responsive) and a low driving pressure (to achieve lung protection). For example, a setting of 30 cm / 18 cm might be reasonable for many patients.
- The ventilator trigger is locked out, to prevent patients from triggering breaths.
- Patients NEED to be deeply sedated-->paralyzed to render them passive on the ventilator
- Ventilation efficacy of each patient can be tracked using an end-tidal CO_2 monitor placed in-line with their own endotracheal tube
  - *In a shortage of $etCO_2$ sensors, it might be possible to use a single sensor and rotate it between patients to spot-check the pCO_2 of each patient sequentially)*
- Permissive hypercapnia will need to be anticipated and managed
- Viral filters should be used to prevent cross-contamination of pathogens between different patients.

Bigger Picture: 5 Ventilators to Provide Personalized Setting to 20 Patients

- Patients must be matched based on relative severity of lung injury (PEEP and FiO2 requirements)
- Imagine that we set up five ventilators:
    - Ventilator 1: Mild injury settings (FiO2 50%, PEEP 10 cm, Peak pressure 20 cm)
    - Ventilator 2: Moderate injury settings (FiO2 60%, PEEP 14 cm, Peak pressure 26 cm)
    - Ventilator 3: High injury setting (FiO2 80%, PEEP 18 cm, Peak pressure 30 cm)
    - Ventilator 4: Refractory hypoxemia settings (FiO2 100%, PEEP 22 cm, peak pressure 35 cm).
    - Ventilator 5: Salvage settings (FiO2 100%, PEEP 22 cm, peak pressure 35 cm, inverse ratio ventilation with inspiratory time >> expiratory time).

Possible Checklist?

Possible strategy for multi-patient ventilation

- **Circuit setup**
  - ❑ Split ventilator tubing ~1-2 times (depending on patient number).
  - ❑ Viral filters to prevent cross-contamination.
  - ❑ Individual etCO2 monitor for each patient (ideally).
- **Ventilator setting**
  - ❑ Pressure control setting with high PEEP and low driving pressure (e.g. 30 cm/18 cm).
  - ❑ Use the least sensitive trigger setting possible, to ideally "lock out" the trigger and prevent any patient from triggering a breath.
- **Sedation**
  - ❑ Patients must be passive on the ventilator (either paralyzed or deeply sedated with agents that suppress respiratory drive such as opioid and/or propofol).
  - ❑ May be easiest to start out with patients being completely paralyzed. Once the circuit is up and running, this may be transitioned to deep sedation (titrated against patient comfort).
- **Monitoring**
  - ❑ Oxygenation of each patient: pulse oximetry
  - ❑ Ventilation of each patient: etCO2 (+/- occasional ABG/VBG)

-The Internet Book of Critical Care, by @PulmCrit

BIPAP vs. CPAP?

- Reasons to avoid BiPAP:
  - In a multicenter cohort of 302 patients with MERS coronavirus, 92% of patients treated with BiPAP failed this modality and required intubation In the
  - FLORALI trial of ARDS patients (with mostly pneumonia of various etiologies), patients randomized to BiPAP did worse compared to patients randomized to HFNC.
- CPAP may be best modality of noninvasive support?
  - Atelectasis leading to hypoxemia seems to be major problem among these patients
  - CPAP can provide greatest amount of mean airway pressure and thus more recruitment

References

- https://www.dispomed.com/detect-soda-lime-exhaustion/
- http://etherweb.bwh.harvard.edu/education/PHILIP/AisysCS2ParticipantGuide.pdf
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