Session 7

Ventilators: Part 2

COVID-19 Preparation for Biomedical Professionals
ECHO Etiquette

- Foundation of love and respect - respond kindly rather than react if you disagree
- It is everybody’s responsibility to keep ECHO a safe space
- Test your equipment ahead of time
- Mute your microphone when not speaking. > Bottom left corner of your screen
- Remember to unmute before speaking
- Introduce yourself before speaking
- Speak clearly, and stay close to your microphone
- IT issues? Send a message through chat/email.

assistHTM@assistinternational.org
<table>
<thead>
<tr>
<th>Time Allotted</th>
<th>Topic</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 minutes</td>
<td>Introduction</td>
<td>Erin</td>
</tr>
<tr>
<td>20 minutes</td>
<td>Didactic – Ventilators: Part 2</td>
<td>Guna &amp; Benjin</td>
</tr>
<tr>
<td>20 minutes</td>
<td>Case Study - Performance Verification Testing</td>
<td>Dr. Masreshaw, Mehamud, Dechasa</td>
</tr>
</tbody>
</table>
Modes Of Mechanical Ventilation

- Controlled Mechanical Ventilation (CMV)
  - Also referred to as VC-CMV
- Assist/control (A/C) Mode
- Synchronized Intermittent Mandatory Ventilation (SIMV)
- Continuous Positive Airway Pressure (CPAP)

<table>
<thead>
<tr>
<th>Mode</th>
<th>Trigger variable</th>
<th>Cycle variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controlled mandatory ventilation (CMV)</td>
<td>Time</td>
<td>Time</td>
</tr>
<tr>
<td>Assist control ventilation (ACV)</td>
<td>Time or patient</td>
<td>Time</td>
</tr>
<tr>
<td>Pressure-control ventilation (PCV)</td>
<td>Time or patient</td>
<td>Time</td>
</tr>
<tr>
<td>Intermittent mandatory ventilation (IMV)</td>
<td>Time</td>
<td>Time</td>
</tr>
<tr>
<td>Synchronized intermittent mandatory ventilation (SIMV)</td>
<td>Time or patient</td>
<td>Time</td>
</tr>
<tr>
<td>Pressure support ventilation (PSV)</td>
<td>Patient</td>
<td>Flow</td>
</tr>
</tbody>
</table>
Controlled Mechanical Ventilation (CMV)

- Patient receives preset number of breaths per minute.
- Classified as **volume control** or **pressure control**:
  - **Volume control** ventilation delivers a fixed tidal volume at a preset respiratory rate.
  - **Pressure control** ventilation delivers a tidal volume at a preset pressure depending on lung condition.
- These modes are used in patients with minimal or no respiratory efforts, ARDS, or flail chest.
- Patient needs adequate sedation & muscle relaxants.
In this mode the ventilator provides a mechanical breath with either a **preset tidal volume** or **peak pressure** every time the patient initiates a breath.

Traditional A/C modes only use a **preset tidal volume** when a **preset peak pressure** is used.

- Also referred to as Intermittent Positive Pressure Ventilation (IPPV).
Synchronized Intermittent Mandatory Ventilation (SIMV)

- Patient is guaranteed a preset number of breaths of a preset tidal volume.
- Between these mandatory breaths, patients may initiate a spontaneous breath.
- This mode allows a synchronization between patient & ventilator.

**VCV** = Volume Control Ventilator

**PCV** = Pressure Control Ventilator
Parameters for Ventilator Testing

- Always start with a pressure check on the system. Settings should be set to 4 bar to 6 bar for ventilator, cylinder, or centralize system. Always keep a back up cylinder.

- Please self test to verified all the sensor and leak tests pass before doing verification.

- **Tidal Volume**: Amount of air delivered with each ventilator breath, usually set at 500 mL.

- **Respiratory Rate (BPM)**: Number of breaths/min. ventilator is to deliver. Usually set at 18 BPM.

- **Positive End Expiratory Pressure (PEEP)**: Pressure maintained in lungs at end of expiration, usually set at 10.

- **Minute Volume or Minute Ventilation (Ve)**: Respiratory rate times the tidal volume RR x vt = Ve. Normal minute volume for adults is 5-10 liters.

- Oxygen output: to verified the output and setting can be change from 21% to 99%

- **I:E ratio**: The ratio of inspiratory time to expiratory time. Set at 1:2 ratio.

- **Alarm**: Verify if there are any high or low alarms on the system. Included: battery alarm, sensor alarm, and power failure alarm.
<table>
<thead>
<tr>
<th>Description</th>
<th>UOM</th>
<th>Set values</th>
<th>Measured values</th>
<th>Limit/Tolerance</th>
<th>Pass</th>
<th>Fail</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. O2 Failure Alarm</td>
<td>N/A</td>
<td>Turn off</td>
<td>Alarm</td>
<td>( )</td>
<td></td>
<td></td>
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<tr>
<td>2. Air Failure Alarm</td>
<td>N/A</td>
<td>Turn off</td>
<td>Alarm</td>
<td>( )</td>
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<td></td>
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<tr>
<td>3. Breathing circuit leak</td>
<td>cmH2O</td>
<td>30</td>
<td>29 to 31</td>
<td>( )</td>
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<td></td>
<td></td>
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<tr>
<td>4. For anesthesia unit</td>
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<td>50</td>
<td>48 to 52</td>
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<tr>
<td>5. O2 Calibration</td>
<td>%</td>
<td>21%</td>
<td>100%</td>
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<td>6. Tidal Volume</td>
<td>ml</td>
<td>300</td>
<td>270 to 330</td>
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<td>With 1 liter test lung/±10%</td>
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<td>600</td>
<td>540 to 660</td>
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<td>7. Breath Rate</td>
<td>bpm</td>
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<td>11 - 13</td>
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<td>23 - 25</td>
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<tr>
<td>8. O2 Concentration</td>
<td>%</td>
<td>21%</td>
<td>19 - 23</td>
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<tr>
<td>If the units have O2/AIR mixer</td>
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<td>47 - 53</td>
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<td>70</td>
<td>67 - 73</td>
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<td>99</td>
<td>92 - 99</td>
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<tr>
<td>9. PEEP</td>
<td>cmH2O</td>
<td>5</td>
<td>3 - 7</td>
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<td>10. I:E Ratio</td>
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</tbody>
</table>
Drive Gas Change Steps (Ex. GE Devices)

1. Remove the rear panel.
   - Note: The O₂ and Air pipeline manifolds have a drive gas connection at the back. The connection not in use is plugged.
Drive Gas Change Steps (Ex. GE Devices)

2. Remove the plug from the new connection.
3. Disconnect the drive gas hose (black hose) from the present connection.
4. Install the plug in this connection (pull on the plug to ensure that it is locked into the fitting).
5. Reroute the drive gas hose so that it does not cause kinks in other tubing.
6. Connect the drive gas hose to the new connection (pull on the hose connector to ensure that it is locked into the fitting).
7. Do a high-pressure leak test.
8. Enter the service mode and select the correct drive gas.
9. Test the primary regulator. Verify that it functions within specifications and will be supplying drive gas to the ventilator.
10. Perform the checkout procedure.
**Single Limb vs. Dual Limb**

- **Single limb** circuits are used in pressure triggered volume ventilators.
- A minimum amount of circuit dead space should be used between the mask and the circuit exhalation valve when using single limb breathing circuit.
- Shorter circuit = less resistance on the circuit.
- Need to use HME filter.
- Aerosol issue with single limb due to exposure near the end circuit for expiratory out. *(COVID)*
- Light weight and single tube management.

- **Dual limb** circuits can be used for both pressure triggered and volume triggered ventilators.
- Minimal dead space.
- Reduced pollution and no exposure with filter.
- Conservation of heat and moisture.
- Inspiratory tube and expiratory tubes meet at the y-piece. The last few centimeters to the patient pass through a single tube.
### Ventilators & Patient Circuit Type

Different technologies used in mechanical ventilation (IV & NIV):

<table>
<thead>
<tr>
<th>Dual limb system with proportional expiratory valve</th>
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</thead>
<tbody>
<tr>
<td>Ventilator</td>
</tr>
<tr>
<td><strong>O2 wall</strong></td>
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<tr>
<td><strong>Air wall</strong></td>
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<tr>
<td><strong>Turbine</strong></td>
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<tr>
<td><strong>Piston</strong></td>
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<tr>
<td><strong>Expiratory limb</strong></td>
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<tr>
<td><strong>Valve Exp</strong></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Single limb system with proximal expiratory valve</th>
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</thead>
<tbody>
<tr>
<td>Ventilateur</td>
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<tr>
<td><strong>O2 wall</strong></td>
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<tr>
<td><strong>O2 low flow</strong></td>
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<tr>
<td><strong>Turbine</strong></td>
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<tr>
<td><strong>Piston</strong></td>
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<tr>
<td><strong>Soufflet</strong></td>
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<tr>
<td><strong>Expiratory valve</strong></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Single limb system with intentional expiratory leak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventilateur</td>
</tr>
<tr>
<td><strong>O2 wall</strong></td>
</tr>
<tr>
<td><strong>O2 low flow</strong></td>
</tr>
<tr>
<td><strong>Turbine</strong></td>
</tr>
<tr>
<td><strong>Inspiratory limb</strong></td>
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</tbody>
</table>
Testing Ventilator

- The placement of the ventilator analyzer is similar to the proximal sensor.
- Testing mode set on BTPS (body temperature and pressure, saturated).

Please check:

- **Proximal flow** sensing has some advantages in terms of trigger sensitivity due to the placement of flow sensors being close in proximity to the patient. The ventilator must have the capability of integrating with this option.

Results: Yield total flow reading, I:E ratio, Vti, Vte, Mv, BPM, total inline pressure, Vtotal, and other important parameters.
Single Limb Test Configuration

Ventilator connection
Similar to Y tubing or dual limb testing connection

Ventilator

Tubing single limb

Ventilator Analyzer

Test Lung
Calibrating Oxygen Sensors:

- An oxygen sensor monitors the oxygen concentration of the gas delivered to the patient. Low oxygen concentration output on the ventilator indicates the sensor must be calibrated with 21% (atmosphere) and 100% oxygen supply.
- After calibration, if the sensor is good but the reading on ventilator display shows contrary results, use another oxygen analyzer to check the output of oxygen from your ventilator.
- Check oxygen supply quality output reading from the cylinder or centerline system for the oxygen purity output by using an oxygen analyzer.
- Sensors are usually replaced after 1-2 years based on the manufacturer's recommendation. It is very important to make sure the oxygen sensors are replaced during the recommended period. As the sensor will start to decrease in reliability and may lead to error messages.
Calibrate Oxygen Sensor

- After replacement, calibrate the sensor with 21% atmosphere and 100% with oxygen supply.
For Clinical Users - Vent Setup

Some issues are beyond what a technician can fix on their own – you can, however, walk the clinical user through ventilator setup and make sure they are complete each step.

The basic steps are:

1. Before Powering the System On:
   - Connect Inspiratory Safety Guard, Exhalation Valve Assembly, and attach Breathing Circuits.

2. Powering the system on:
   - Connect Air & Oxygen supply source, plug device into an outlet, and press the power switch.

3. Patient Setup:
   - Select “New Patient” and choose “Adult,” “Pediatric,” or “Neonatal” patient type.
   - Enter Patient ID & other information such as gender/height/weight.
   - Enter tube information.

4. Perform a System Check

5. Set a Ventilation Mode & Backup Mode

6. Start Patient Ventilation

* Note that the BMET should never be making decisions about items such as ventilation mode for use on a patient. A BMET should just be guiding the clinical user through the settings.

These steps are from a GE Carescape R860 Quick Reference Guide found on the Ventilator Training Alliance website here.
# Common Errors & Troubleshooting

## Problem
- System leaks
- Circuit malfunction or disconnection
- Inadequate oxygen and alarm
- Inappropriate ventilator support mode, trigger sensitivity, inspiratory flow setting, cycle variable, PEEP setting, etc.

## Solution
- Do self test regularly by using self test mode.
- Always use a test lung during self test mode to verify if the circuit is working.
- Verify oxygen purity by using an oxygen analyzer.
- Check the cylinder pressure and centralized pressure. Should be in the range of 4 bar to 6 bar/450Kpa to 680 Kpa.
- If all the modes are working, verify using test lung before applying on the patient. If there is still an issue, please refer to manual or do testing with an analyzer.
### Common Errors: Flow Sensor

**Problem**
- Cannot read oxygen flow sensor.
- Cannot read exhalation flow sensor.

**Solution**
- Enter diagnostic mode service manual (depends on brand and model).
- Verify oxygen flow sensor cable connections. Replace oxygen flow sensor.
- **Calibrate sensor again after replacement.**
Common Errors: Gas Supply Source

**Problem**
- Lack of supply, or incorrect regulator pressure

**Solution**
- Centralized gas supply is preferred.
- If cylinders are used they should be full.
- Spare cylinders should be available.
- Check the cylinder pressure and centralized pressure if it is in the range of 4 bar to 6 bar/ 450Kpa to 680 Kpa.
- Check the oxygen supply daily for purity with an oxygen analyzer.
Power & Battery Alarm Precautions

Problem
- Battery issues
- Power source issues

Solution
- Plug into a grounded AC power unit with correct voltage receptacle.
- Secure the power cord properly.
- Check the battery level before connecting.
- Charging should be carried out regularly.

**Remember unit is for short term use.**
Clinical User Precautions

Precautions

- Always make sure to do a self test with the ventilator.
- **Properly trained personnel use ONLY**
- Familiarize staff with operator’s manual before using on a patient.
  - Note: one manufacturer’s manual may not exactly match with other brands.
- Monitor the functioning state of the ventilator while in use.
- **Familiarize staff with alarm system.**
- Do not place ventilators in a combustible or explosive environment – keep away from heat sources and other hazards.
BMET Precautions

- Qualified personnel should undertake servicing.
- Follow test specifications mentioned in service manual.
- Perform general servicing at regular intervals – typically every 3 - 6 months, depending on use and manufacturer recommendations.
- Run prescribed tests and calibrations before using the ventilator
- Ensure that ventilators pass all the tests before putting them in to clinical use.
Alarms:

All ventilators are equipped with visual and audible alarms which notify user problems.

VC mode – High Pressure alarm
PC mode – Low TV alarm
PSV/CPAP – Apnea alarm

Other Key Points:

• Never ignore an alarm.
• Find out for yourself what alarm is on. Refer to user manuals.
• Don’t mute the alarm on a regular basis; find the source first.
Low Alarm

**Problem**
- LOW PRESSURE / LOW TIDAL VOLUME/APNEA
- Patient circuit leak

**Solution**
Check this following items:
- Remove inspiratory bacteria filter and external oxygen sensor and try another patient circuit.
- Block outlet of exhalation flow sensor while running leak test. If leak stops, replace exhalation valve.
- Verify that connection between the oxygen flow sensor and oxygen valve is tight.
- Inadequate flow - check with analyzer and calibrate the flow sensor.
Low Alarm

**Problem**
- Low inhalation pressure.

**Solution**
- Check for patient circuit leaks.
- Verify that O-ring is present in external oxygen sensor or bypass oxygen sensor (depends on brand).
- Check inhalation pressure transducer.
- Check the connection between the inspiratory manifold and inspiratory autozero solenoid.
- Check for kinks or cuts in the tube between inhalation autozero solenoid and inhalation pressure sensor.
Problem

- The measured peak inspiratory pressure is greater than set level because of increased airway resistance.
- High pressure on incoming driving gas supply.
- HIGH PRESSURE/ HIGH TIDAL VOLUME

Solution

- Check for water in the tube - clean or replace with new tubing.
- Filter block (replace).
- Water trap problem (replace).
- Partial / complete block – tubing.
- Kinking of tube (replace or get smooth connection).
- Check and reduce the high input pressure in ventilator system.
Case Study: Work in Ethiopia

So far, we have done performance verification tests on 24 ventilators in about one week.
Case Study

Performance Verification Test (PVT)
- Electrical safety test
- Running Extended Self-Test (EST)
- Conduct parameter test using ventilator analyzer
  - Setting up the ventilator
  - Setting up the ventilator analyzer
  - Sensor verification/calibration
    - Flow sensor and oxygen sensor

Challenges
- Test Lung
- Analyzer configuration (ATP vs BTPS)
- Altitude
- Flow Sensor Calibration
- Patient Circuit
Electrical Safety Test

Tests Needed According to IEC 60601 Standards:

- Line Voltage
- Device Current
- Earth Resistance
- Earth Leakage Current
  - Normal condition
  - Single fault condition
- Enclosure Leakage Current
  - Normal condition
  - Single fault condition
Running Extended Self-Test

- Enter the diagnostic mode – example below shows a Phillips V200.
  - Simultaneously press ALARM RESET and 100% O₂.
  - You follow the instructions and finish the EST.
  - Never use the ventilator if does not pass EST.

Never initiate an EST while the patient is connected to the ventilator.
The high airway pressures and gas flows generated during EST can injure a patient.
Conducting Parameter Testing

**Setting up the ventilator**
- Check if the altitude setting is correct and write it down.
- Once you are in the diagnostic mode, click “user Config” to set altitude. Example shown is a Phillips V200.
- In Addis, it is 7726 feet – you can find this via google, or use a barometer. This is sometimes found on your analyzer.

### Case Study: PVT & Challenges

![Image of a ventilator setup]

**Summary**

**Discussion**
Conducting Parameter Testing

- **Setting up the Ventilator Analyzer**
  - Ventilator analyzers used:
    - Fluke VT Mobile
    - Fluke VT Plus HF
  - For pressure measurement, set the analyzer to ATP.
    - ATP = Ambient Temperature and Pressure
  - For volume and flow measurement, set the analyzer to BTPS.
    - BTPS = Body Temperature, Pressure and Saturation
Conducting Parameter Testing

(Air) Flow Sensor Verification:
- Simultaneously press ALARM RESET and 100% O₂
- Connect the Ventilator and Analyzer as shown.
  - Connect a tube from the ventilator main outlet to the high flow port of a calibrated analyzer.
- Set the analyzer to read LPM.
- Set the analyzer’s gas flow to air.
- Touch Safety to energize the safety solenoid.
- Check that set air flow corresponds to measured flow.
  - If reading is out of range, run it for multiple cycles (e.g. 10 - 20 cycles) and check reading again.
Conducting Parameter Testing

(O) Flow Sensor Verification:
- Air Flow set: 50 LMP
- Reading: 48.9 LMP

Oxygen Sensor Verification is very similar; follow same procedure, using the “oxygen button.”

Phillips V200

<table>
<thead>
<tr>
<th>Air Flow (LPM)</th>
<th>Range (LPM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 LPM</td>
<td>4.5 to 5.5 LPM</td>
</tr>
<tr>
<td>10 LPM</td>
<td>9 to 11 LPM</td>
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<tr>
<td>20 LPM</td>
<td>18 to 22 LPM</td>
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<tr>
<td>50 LPM</td>
<td>45 to 55 LPM</td>
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<tr>
<td>100 LPM</td>
<td>90 to 110 LPM</td>
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<tr>
<td>120 LPM</td>
<td>108 to 132 LPM</td>
</tr>
<tr>
<td>165 LPM</td>
<td>148.5 to 181.5 LPM</td>
</tr>
</tbody>
</table>
Conducting Parameter Testing

(Air) Flow Sensor Verification:
- Air Flow set: 100 LMP
- Reading: 95.3 LMP

Typically during calibration, run the following tests in order:
- Low
- Medium
- High
- Low/Zero

Phillips V200

<table>
<thead>
<tr>
<th>Flow Rate (LPM)</th>
<th>Flow Rate Range (LPM)</th>
</tr>
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<tbody>
<tr>
<td>5 LPM</td>
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</tr>
</tbody>
</table>
Challenges

- **Test Lung**
  - Be aware that test lungs [1 L] need to be replaced after continuous wear. Using old test lungs can affect measurement results (e.g. Tidal Volume).

- **Analyzer configuration (ATP vs BTPS)**
  - For Pressure measurement, set the analyzer to ATP
    - ATP = Ambient Temperature and Pressure
  - For Volume and Flow measurement, set the analyzer to BTPS
    - BTPS = Body Temperature, Pressure and Saturation

- **Altitude**
  - Make sure altitude is set correctly as gas flow and pressure accuracy tests require correct altitude information.
  - Default is set for sea level, and could be very different depending on location.

- **Flow Sensor Calibration**
  - Be aware that the flow sensor may need calibration (especially if the machine has not been used for a long time) - this affects flow measurement and ultimately tidal volume.

- **Patient Circuit**
  - Measurements are affected by temperature, so you can’t hold the tubing while running tests. Set tubing on a stable surface instead.
Thank You!
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