By the end of this course, you should be able to:

• Describe Compliance, Elastance and Airway resistance
• Categorize the Anesthesia Delivery System ventilation modes
• Understand Trigger Window, Flow Trigger, End of Breath and Rise Rate
• Identify and describe the Anesthesia Delivery System modes of ventilation
• Describe 3 clinical scenarios where Pressure Control Ventilation-Volume Guarantee would be used
• Understand when PSVPro or CPAP + PSV should be used
• Discuss advantages and disadvantages for Volume Control, Pressure Control, Pressure Control Ventilation-Volume Guarantee
Mechanics of Ventilation
Lung Compliance

Compliance = $\Delta$Volume/$\Delta$Pressure (mL/cmH2O)

Change in volume over the change in pressure

- A measure of the ease of expansion of the lungs and thorax, determined by pulmonary volume and elasticity
- A high degree of compliance indicates a loss of elastic recoil of the lungs, as in old age or emphysema
- Decreased compliance means that a greater change in pressure is needed for a given change in volume, as in atelectasis, edema, fibrosis, pneumonia, or absence of surfactant

**Static Compliance** = Exhaled Tidal Volume (Vte)/Plateau Pressure (Pplat) – Positive End Expiratory Pressure (PEEP)

**Dynamic Compliance** = Exhaled Tidal Volume (Vte)/Peak Inspiratory Pressure (PIP) – Positive End Expiratory Pressure (PEEP)

**Normal adult compliance:** 40-70 mL/cmH2O

**In children:** About 1mL/cmH2O/kg
Elastance

Elastance = ΔPressure/ ΔVolume (cmH2O/mL)
Change in pressure over the change in volume

A measure of the tendency of something to recoil toward its original dimensions upon removal of a distending or compressing force

Compliance and elastance are inversely related
• If compliance increases, then elastance decreases
• If compliance decreases, then elastance increases


Airway Resistance

Raw = $\Delta$ Pressure/Flow (cmH2O/L/sec)

*Change in pressure over flow*

### Types of flow:
- **Laminar flow:** Smooth, even non-tumbling flow
- **Turbulent flow:** Rough, tumbling uneven flow pattern
  - The pressure gradient necessary to maintain turbulent flow is much higher than that necessary to maintain laminar flow
- **Tracheobronchial flow:** A combination of laminar and turbulent flow which is maintained throughout the respiratory system

Airway resistance is the friction caused by the movement of air throughout the respiratory system.

Airway resistance decreases with increased airway diameter, bronchodilation, laminar flow and increase in lung volume.

Airway resistance increases with decreased airway diameter, bronchoconstriction, turbulent flow and decrease in lung volume.

**Normal airway resistance** is 0.5-2.5cmH2O/L/sec at a flow rate of 0.5 L/sec

Modes of Ventilation Categories
Modes of Ventilation: Introduction and Overview
Define categories of ventilation

<table>
<thead>
<tr>
<th>Control modes</th>
<th>Synchronized modes</th>
<th>Support modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive pressure ventilation in which the ventilator is in control mode, with its cycle entirely controlled by the apparatus and not influenced by the patient’s efforts at spontaneous ventilation.</td>
<td>Synchronized Intermittent Mechanical Ventilation is a variation of IMV, in which the ventilator breaths are synchronized with patient inspiratory effort, with added pressure support.</td>
<td>The patient initiates every breath and the ventilator delivers support with the preset pressure value. With support from the ventilator, the patient also regulates his own respiratory rate and tidal volume.</td>
</tr>
</tbody>
</table>
Ventilator mode can be defined as a set of operating characteristics that control how the ventilator functions.

**Operating mode can be described by:**

- The way a ventilator is triggered into inspiration and cycled into expiration
- What variables are limited during inspiration
- Whether or not the mode allows mandatory, spontaneous, or supported breaths
Modes of Ventilation: Control Modes

Control modes: Introduction and overview

- Each breath is initiated, limited and terminated by the ventilator
- Patients can breathe spontaneously between control breaths, but the ventilator does not respond to the spontaneous effort

<table>
<thead>
<tr>
<th>Mode</th>
<th>Primary Settings</th>
<th>Inspiratory Flow Pattern</th>
<th>Patient Synchrony</th>
</tr>
</thead>
<tbody>
<tr>
<td>VCV</td>
<td>Tidal Volume</td>
<td>Constant</td>
<td>No</td>
</tr>
<tr>
<td>PCV</td>
<td>Inspiratory Pressure</td>
<td>Decelerating</td>
<td>No</td>
</tr>
<tr>
<td>PCV-VG</td>
<td>Tidal Volume</td>
<td>Decelerating</td>
<td>No</td>
</tr>
</tbody>
</table>
Synchronized Intermittent Mechanical Ventilation in which the ventilator breaths are synchronized with patient inspiratory effort, with added pressure support

**Modes of Ventilation: Synchronized Modes**

**Synchronized modes:** Introduction and overview

Synchronized Intermittent Mechanical Ventilation in which the ventilator breaths are synchronized with patient inspiratory effort, with added pressure support

<table>
<thead>
<tr>
<th>Mode</th>
<th>Primary Settings</th>
<th>Inspiratory Flow Pattern</th>
<th>Patient Synchrony</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIMV-VCV</td>
<td>Tidal Volume</td>
<td>Constant</td>
<td>Yes</td>
</tr>
<tr>
<td>SIMV-PCV</td>
<td>Inspiratory Pressure</td>
<td>Decelerating</td>
<td>Yes</td>
</tr>
<tr>
<td>SIMV-PCV-VG</td>
<td>Tidal Volume</td>
<td>Decelerating</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Modes of Ventilation: Support Modes

**Support modes:** Introduction and overview

The ventilator supplies pressure support in response to the spontaneous breathing with no set rate; pressure support can also be added to SIMV modes of ventilation.

The patient must be spontaneously breathing and the ventilator must recognize and respond to the spontaneous effort, based on the patient’s inspiratory flow.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Primary Settings</th>
<th>Inspiratory Flow Pattern</th>
<th>Patient Synchrony</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPAP/PS</td>
<td>PEEP</td>
<td>Decelerating</td>
<td>Yes</td>
</tr>
<tr>
<td>PSVpro</td>
<td>Pressure Support</td>
<td>Decelerating</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Adapted from DOC1931778

GEHC Anesthesia Modes of Ventilation – USA JB7612SUS | April 30, 2020

Adapted from DOC1931778
Ventilation Mode Features:
- Trigger Window
- Flow Trigger
- End of Breath
- Rise Rate
Trigger Window

- A percentage of end expiratory time that a patient can trigger a mechanical breath
  - Adjustable from 0-80%
- If the ventilator senses the beginning of inspiration within the trigger window, it delivers the next volume, pressure or PCV-VG breath and inspiratory time set on the ventilator
- If the patient does not make an inspiratory effort within the trigger window, the ventilator will deliver a machine breath to the patient
- Any breath outside of the trigger window will be a pressure supported breath, if set
- Available in all SIMV modes
Flow Trigger

- Flow Triggering: Synchronizes SIMV and Pressure supported breath delivery with the patient’s effort
- Flow Trigger: Adjustable negative flow (0.2 – 10 L/min) needed to trigger a mechanical breath
- Measured by the inspiratory flow sensor
- Improves synchronization of breaths decreasing a patient’s tendency to fight the ventilator
End of Breath

The inspiratory phase of the pressure supported breath will end when the set end of breath is reached.

- Range: 5-75% of peak inspiratory flow

Example: End of breath is set to 30%, peak flow is 40 L/min, when the peak flow drops to 12 L/min the pressure supported breath will terminate and go to the expiratory phase.
Rise Rate

Reaches set pressure or pressure support level as quickly as possible without an overshoot
• Range: Auto, 1-10
• 1 is the slowest, 10 the fastest

<table>
<thead>
<tr>
<th>Rise Rate</th>
<th>Pressure</th>
<th>Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Set Pressure

April 30, 2020

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Modes of Ventilation: Control Modes
Volume Control Ventilation (VCV)

- The ventilator delivers mechanical breaths of the set tidal volume at intervals based on the set respiratory rate
  - The amount of pressure required to deliver the tidal volume depends on the patient’s lung compliance and resistance
- The ventilator calculates an inspiratory flow based on the set tidal volume, inspiratory time and Tpause, if set
  - Flow is constant and maintained during the inspiratory phase while airway pressure is below the pressure limit
  - Adjustable pressure limit terminates the breath if peak pressure is reached
- Ventilator can compensate for breathing system compliance, fresh gas flow, and moderate breathing system leaks
- Inspiratory pause is available to improve gas distribution
- Ideal for a patient with normal compliance, low airway resistance and need for consistent, non-synchronized breaths
Volume Control Ventilation (VCV)

1. Paw waveform
2. Tinsp
3. Insp pause
4. Texp
5. PEEP
6. Flow waveform
7. TV
Pressure Control Ventilation (PCV)

- The ventilator delivers mechanical breaths at the set inspiratory pressure level during inspiration.
- The ventilator calculates the inspiratory time from the frequency and I:E ratio settings.
  - The tidal volume delivered depends on the patient's lung compliance.
- A high initial flow pressurizes the circuit to the set inspiratory pressure ($P_{insp}$).
  - The gas flow to the patient decreases after the pressure level reaches the pressure setting.
  - The flow then decreases to maintain the set pressure for the remaining inspiratory time.
- Pressure sensors in the ventilator measure patient airway pressure.
- The ventilator automatically adjusts the flow to maintain the set inspiratory pressure.
Pressure Control Ventilation (PCV)

1. Paw waveform
2. Tinsp
3. Texp
4. Pinsp
5. PEEP
6. Flow waveform
7. Tidal volume
The ventilator delivers mechanical breaths of the set tidal volume at intervals based on the set respiratory rate. For each breath, the ventilator adjusts the inspiratory pressure to use the lowest pressure required to deliver the tidal volume:
- Delivers breaths with the efficiency of pressure controlled ventilation
- Compensates for changes in the patient’s lung characteristics

To determine the patient’s lung compliance, the ventilator delivers volume-controlled breath:
- Based on the patient’s lung compliance, the inspiratory pressure is established for subsequent breaths
- When adjusting the inspiratory pressure the following pressure range is used:
  - Low end: PEEP+2 cmH2O
  - High end: Pmax-5 cmH2O
- The difference in inspiratory pressure between breath does not exceed +/- 3 cmH2O

If a high airway pressure alarm is active due to current breath, the next breath’s target will be 0.5 cmH2O less than the current breath’s pressure target.
Pressure Control Ventilation-Volume Guarantee (PCV-VG)

1. Paw waveform
2. Tinsp
3. Texp
4. Variable pressure to deliver desired TV
5. PEEP
6. Flow waveform
7. TV
PCV-VG Clinical Scenarios
Laparoscopic procedures

- Adjusts the Pinsp automatically to the increasing intra-abdominal pressure
- Helps to reduce number of interactions with ventilator compared with PCV
- May sustain PaCO₂ better than PCV
- Manages additional CO₂ load caused by pneumoperitoneum
Major trauma and anesthesia ventilation

- Lung protective ventilation: guaranteed low volume ventilation, lowest possible Pinsp
- Management of pCO$_2$-stability due to volume guarantee
- Automatic management of Pinsp – reduces workload – saves anaesthetic resources in this highly demanding environment
Cardiac anesthesia

• Open chest surgery – prevents over inflation of lungs when compliance suddenly increases

• Lung protective ventilation: guaranteed low volume ventilation at the lowest possible Pinsp

• Management of pCO₂-stability due to volume guarantee – very important in patients with pulmonary hypertension

• Automatic adjustment of Pinsp – reduces workload – saves anesthetic resources in this highly demanding environment
Modes of Ventilation: Synchronized Modes
The ventilator delivers synchronized mechanical breaths of a set tidal volume at intervals based on a set respiratory rate. All other spontaneous efforts are delivered as pressure-supported breaths.

- The amount of pressure required to deliver the tidal volume depends on the patient’s lung compliance and resistance.
- The ventilator will always deliver the specific number of breaths per minute the clinician has set.
- I:E is replaced by an inspiratory time (Tinsp).
- Between machine breaths, the patient can breathe spontaneously at the rate, tidal volume and timing that the patient desires.

The ventilator calculates an inspiratory flow based on the set tidal volume, inspiratory time and Tpause, if set.

- Flow is constant and maintained during the inspiratory phase while airway pressure is below the pressure limit.
- Adjustable pressure limit terminates the breath if peak pressure is reached.

Spontaneous breaths that occur are indicated by a color change in the waveform.

Trigger window, Rise Rate, Flow Trigger and End of Breath are all active in this mode.
Synchronized Intermittent Mandatory Ventilation Volume Control Ventilation (SIMV VCV)

1. Pressure waveform
2. Mandatory SIMV breath
3. Pressure supported breath
4. Inspiratory time
5. PEEP
6. Expiratory time
7. Flow waveform
8. Tidal volume
Synchronized Intermittent Mandatory Ventilation Pressure Control Ventilation (SIMV PCV)

• The ventilator delivers synchronized mechanical breaths at the set inspiratory pressure level for a set inspiratory time at intervals based on the set respiratory rate. All other spontaneous efforts are delivered as pressure-supported breaths
  – The tidal volume delivered depends on the patient’s lung compliance
  – The ventilator will always deliver the specific number of breaths per minute the clinician has set
  – I:E is replaced by an inspiratory time (Tinsp)
  – Between machine breaths, the patient can breathe spontaneously at the rate, tidal volume and timing that the patient desires

• A high initial flow pressurizes the circuit to the set inspiratory pressure
  – The gas flow to the patient decreases after the pressure level reaches the pressure setting
  – The flow then decreases to maintain the set pressure for the remaining inspiratory time

• The ventilator automatically adjusts the flow to maintain the set inspiratory pressure

• Spontaneous breaths that occur are indicated by a color change in the waveform

• Trigger window, Rise Rate, Flow Trigger and End of Breath are all active in this mode
Synchronized Intermittent Mandatory Ventilation
Pressure Control Ventilation (SIMV PCV)

1. Paw waveform
2. Tinsp
3. Spontaneous breathing period
4. Trigger window
5. Pressure supported breath
6. Pinsp
7. Flow waveform
8. Tidal volume
Synchronized Intermittent Mandatory Ventilation Pressure Control
Ventilation-Volume Guarantee (SIMV PCV-VG)

• The ventilator delivers synchronized mechanical breaths of the set tidal volume at intervals based on the set respiratory rate. For each mechanical breath, the ventilator adjusts the inspiratory pressure to use the lowest pressure required to deliver the tidal volume. All other spontaneous efforts are delivered as pressure-supported breaths
  – Delivers breaths with the efficiency of pressure controlled ventilation
  – I:E is replaced by an inspiratory time (Tinsp)
  – Between machine breaths, the patient can breath spontaneously at the rate, tidal volume and timing that the patient desires
  – Compensates for changes in the patient’s lung characteristics

• To determine the patient’s lung compliance, the ventilator delivers volume-controlled breath
  – Based on the patient's lung compliance, the inspiratory pressure is established for subsequent breaths
  – When adjusting the inspiratory pressure the following pressure range is used:
    • Low end: PEEP+2 cmH2O
    • High end: Pmax-5 cmH2O
  – The difference in inspiratory pressure between breath does not exceed +/- 3 cmH2O

• If a high airway pressure alarm is active due to current breath, the next breath’s target will be 0.5 cmH2O less than the current breath’s pressure target

• Spontaneous breaths that occur are indicated by a color change in the waveform
• Trigger window, Rise Rate, Flow Trigger and End of Breath are all active in this mode
Synchronized Intermittent Mandatory Ventilation Pressure Control
Ventilation-Volume Guarantee (SIMV PCV-VG)

1. Paw waveform
2. Tinsp
3. Spontaneous breathing period
4. Trig window
5. Variable pressure to deliver desired TV
6. PEEP
7. Flow waveform
8. TV
Modes of Ventilation: Support Modes
Pressure Support Ventilation Pro (PSVPro)

- The ventilator provides a constant support pressure once it senses the patient has made an inspiratory effort
  - Intended to be used on spontaneously breathing patients
  - The clinician sets the pressure support and PEEP levels
  - Patient initiates spontaneous breaths and determines respiratory rate, timing, and tidal volume

- An apnea backup mode of SIMV PCV is provided if the patient stops breathing
  - Backup time can be set between 10-30 seconds
  - The clinician sets the backup inspiratory pressure (Pinsp), respiratory rate (RR) and inspiratory time (Tinsp)
  - The Backup Mode active alarm will show until PSVPro is reinstated or until another ventilation mode is selected
    - PSVPro automatically resumes when the ventilator registers the number of consecutive patient triggered breath set for Exit Backup
    - Exit Backup range Off, 1-5 spontaneous breaths
    - When Exit Backup is set to off, the user must reselect PSVPro mode to reactivate PSVpro

- Spontaneous breaths that occur are indicated by a color change in the waveform
- Trigger window, Rise Rate, Flow Trigger and End of Breath are all active in this mode
Pressure Support Ventilation Pro (PSVPro)

1. Airway pressure (Paw) waveform
2. Pressure support (PS)
3. Inspiratory time (Backup Tinsp)
4. PEEP
5. Backup breath
6. Backup Pinsp
7. Flow waveform
8. Tidal volume (TV)
Continuous Positive Airway Pressure + Pressure Support Ventilation (CPAP + PSV)

- The ventilator provides a constant support pressure once it senses the patient has made an inspiratory effort
  - Intended to be used on spontaneously breathing patients
  - The clinician sets the pressure support and PEEP levels
  - Patient initiates spontaneous breaths and determines respiratory rate, timing, and tidal volume

- If the spontaneous inspiratory effort does not occur within the delay period, the ventilator delivers pressure controlled breaths at the preset inspiratory pressure to meet the set minimum rate
  - The delay period calculation is \(60\text{s}/\text{minimum rate} + \left[(60\text{s}/\text{minimum rate}) - \text{previous measured breath period}\right]\)
  - Pressure support (Psupport) and inspiratory pressure (Pinsp) settings are linked
    - When the pressure support (Psupport) setting is changed the inspiratory (Pinsp) is automatically adjusted to match the Psupport setting
    - The link is broken by changing the Pinsp setting through the vent mode menu

- Spontaneous breaths that occur are indicated by a color change in the waveform

- Trigger window, Rise Rate, Flow Trigger and End of Breath are all active in this mode
Continuous Positive Airway Pressure + Pressure Support Ventilation (CPAP + PSV)

1. Airway pressure (Paw) waveform
2. Pressure support (PS)
3. Inspiratory time (Backup Tinsp)
4. PEEP
5. Minimum rate backup breath
6. Backup Pinsp
7. Flow waveform
8. Tidal volume (TV)
When and why use PSVPro or CPAP + PSV instead of a manual bag for Spontaneous Breathing?

<table>
<thead>
<tr>
<th>PSVPro and CPAP + PSV indications</th>
<th>Using PSVpro or CPAP + PSV instead of manual bag</th>
</tr>
</thead>
<tbody>
<tr>
<td>All operations where spontaneous breathing does not interfere with surgical procedure</td>
<td>Support use of Laryngeal Mask Airway (LMA)</td>
</tr>
<tr>
<td>Cases with spontaneous breathing using an artificial airway</td>
<td>Never exceeds the clinician-selected pressure level</td>
</tr>
<tr>
<td>Ideal for laryngeal mask (Ppeak reduced compared with mechanical ventilation with equal TV)</td>
<td>Decreases work of breathing (through the circuit)</td>
</tr>
<tr>
<td></td>
<td>Overcomes resistance of breathing circuit</td>
</tr>
<tr>
<td></td>
<td>Counters the decrease of Functional Residual Capacity (FRC)</td>
</tr>
</tbody>
</table>
Modes of Ventilation: Advantages and Disadvantages
Advantages and Disadvantages of Volume Control, Pressure Control and Pressure Control Ventilation - Volume Guarantee

<table>
<thead>
<tr>
<th></th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Volume Control</strong></td>
<td>• Constant tidal volume</td>
<td>• Constant flow rate</td>
</tr>
<tr>
<td></td>
<td>• Consistent alveolar ventilation</td>
<td>• Increase in potential asynchronies</td>
</tr>
<tr>
<td></td>
<td>• Easily identify changes in PIP and Pplat as respiratory mechanics change</td>
<td>• Varying pressures</td>
</tr>
<tr>
<td><strong>Pressure Control</strong></td>
<td>• PIP and peak alveolar pressures are constant</td>
<td>• Varying tidal volumes</td>
</tr>
<tr>
<td></td>
<td>• Flow varies with patient demand</td>
<td></td>
</tr>
<tr>
<td><strong>Pressure Control Ventilation-Volume Guarantee</strong></td>
<td>• Targeted tidal volume</td>
<td>• Pressure adjusts based on the tidal volume of the last breath</td>
</tr>
<tr>
<td></td>
<td>• Pressure automatically adjusts based on lung compliance and airway resistance</td>
<td>• Asynchronies may occur with variable patient effort</td>
</tr>
<tr>
<td></td>
<td>• Decelerating waveform</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Variable inspiratory flow to meet patient’s demand</td>
<td></td>
</tr>
</tbody>
</table>
Conclusion

This concludes the GE Anesthesia Delivery Systems Modes of Ventilation.

In this course, you learned about:

• Compliance, Elastance and Airway resistance
• GE Anesthesia Delivery Systems ventilation modes categories
• Trigger Window, Flow Trigger, End of Breath and Rise
• The GE Anesthesia Delivery Systems modes of ventilation
• Clinical scenarios where PCV-VG could be used
• When to use PSVPro or CPAP + PSV
• The advantages and disadvantages of volume control, pressure control, pressure regulated volume control and airway pressure release ventilation

Disclaimers
Always refer to device manufacturers user reference manual for specific application of your GE Anesthesia Delivery System. Use this information as guidance and each patient may require clinical decisions not covered in this information. Ensure proper clinically appropriate alarm limits are set and monitored.