MODES OF MECHANICAL VENTILATION

Mazen Kherallah, MD, FCCP
Points of Discussions

- Advanced Basics:
  - Flow and Time
  - Limit and cycling
  - Rise Time
  - Volume vs Pressure Control
- Mandatory Modes of Ventilation
  - Controlled Mandatory Ventilation (CMV or IPPV)
- Triggered Modes of Ventilation
  - Continuous Positive Airway Pressure (CPAP)
  - Pressure Support Ventilation (PSV)
- Hybrid Modes of Ventilation
  - Assist Control Mode (A/C)
  - Synchronized Intermittent Mandatory Ventilation (SIMV)
RESPIRATORY CYCLE

Inspiration

Expiration

Transition = Inspiratory Cycling

Transition = Expiratory Cycling
RELATIONSHIP BETWEEN TIDAL VOLUME, INSPIRATORY TIME AND FLOW

Volume

$V_T 3$

$V_T 1$

$V_T 2$

Flow = 37.5 L/min

Flow = 30 L/min

Flow = 15 L/min

$T_{ia}$
RELATIONSHIP BETWEEN TIDAL VOLUME, INSPIRATORY TIME AND FLOW

Flow = 60 L/min
Flow = 30 L/min
Flow = 20 L/min

$V_T \text{1}$

$T_i \text{b}$ $T_i \text{c}$ $T_i \text{a}$

Time

Volume
PRESSURE LIMITED BREATH
Expiratory Flow Cycling
RISE TIME

Pressure vs. Time

Flow vs. Time

Volume vs. Time

Time

$T_i$ $T_e$
MANDATORY, SPONTANEOUS AND TRIGGERED INSPIRATORY CYCLING
**Volume Controlled Inflation**

- **Pressure**
- **Flow**
- **Volume**

- Tidal Volume

- \( T_I \)
- \( T_E \)

**Time**
If compliance decreases the pressure increases to maintain the same VT
VOLUME CONTROL WITH END-INSPIRATORY PAUSE
PRESSURE CONTROLLED INFLATION

- Pressure
- Flow
- Volume

- Rise Time
- Peak Inspiratory Flow
- Tidal Volume

Time

$T_I$ $T_E$
Inspiration Expiration

Volume/Flow Control

Pressure

Volume

Flow

Pressure Control

Inspiration Expiration

Time (s)

Pressure

Volume

Flow

Time (s)
TRIGGERED MODES OF VENTILATION

CPAP and PSVV
SPONTANEOUS BREATHING

Pressure (cm H$_2$O)

Flow (L/m)

Volume (mL)

Time (sec)
CONTINUOUS POSITIVE AIRWAY PRESSURE (CPAP)

- Pressure (cm H$_2$O)
- Flow (L/m)
- Volume (mL)
- Time (sec)
Pressure Support Ventilation (PSV)

Set PS Level

Longer Inspiration

Better Efforts

Flow Cycling

Patient Triggered, Flow Cycled, Pressure limited Mode
CPAP+PSV

Pressure (cm H₂O)

Flow (L/m)

Volume (mL)

Time (sec)

Patient Triggered, Flow Cycled, Pressure limited Mode
## Triggered Modes of Ventilation

### Pressure Support Ventilation

<table>
<thead>
<tr>
<th>Control</th>
<th>Trigger</th>
<th>Limit</th>
<th>Target</th>
<th>Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>Patient</td>
<td>Pressure</td>
<td></td>
<td>Flow</td>
</tr>
</tbody>
</table>

**Patient Triggered Flow Cycled Ventilation**
PRESSURE OR VOLUME-TARGETED VENTILATION

**Advantages**
- Full to partial ventilatory support
- Augments the patients spontaneous VT
- Decreases the patient’s spontaneous respiratory rate
- Decreases patient WOB by overcoming the resistance of the artificial airway, vent circuit and demand valves
- Allows patient control of TI, Vm I, f and VT
- Set peak pressure
- Prevents respiratory muscle atrophy
- Facilitates weaning
- Improves patient comfort and reduces need for sedation
- May be applied in any mode that allows spontaneous breathing, e.g., VC-SIMV, PC-SIMV

**Disadvantages**
- Requires consistent spontaneous ventilation
- Patients in stand-alone mode should have back-up ventilation
- VT variable and dependant on lung characteristics and synchrony
- Low exhaled $V_E$
- Fatigue and tachypnea if PS level is set too low
MANDATORY MODES OF VENTILATION
CMV or IPPV
## Mandatory Modes of Ventilation

CMV

<table>
<thead>
<tr>
<th>Control</th>
<th>Trigger</th>
<th>Limit</th>
<th>Target</th>
<th>Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Or Volume</td>
<td>Time</td>
<td></td>
<td></td>
<td>Time</td>
</tr>
</tbody>
</table>

Time Triggered Time Cycled Ventilation
CONTROL MODE
(PRESSURE-TARGETED VENTILATION)

Time Triggered, Pressure Limited, Time Cycled Ventilation
**CONTROL MODE**
*(VOLUME-TARGETED VENTILATION)*

- **Flow (L/m)**
- **Pressure (cm H$_2$O)**
- **Volume (mL)**

- **Time Triggered, Flow Limited, Volume Cycled Ventilation**

- Time Cycling
- Preset $V_T$
- Volume Cycling

*Dependent on $C_L$ & $R_{aw}$*
### Pressure or Volume-Targeted Ventilation

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Decreases the work of breathing (WOB)</td>
<td>- Not able to assist the ventilator</td>
</tr>
<tr>
<td>- Helps maintain a normal PaCO2</td>
<td></td>
</tr>
</tbody>
</table>
MV high !!!

<table>
<thead>
<tr>
<th>IPPV</th>
<th>Adult</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **AutoFlow**
- **Pmean**: 8 mbar
- **PEEP**: 5 mbar
- **Ppeak**: 12 mbar
- **Ppeak > 50**
- **Flow**: 14 L/min
- **f mand**: 1.6
- **f total**: 14
- **VTASB**: --
- **VT**: 0.520 L

- **Sigh**: 1:1
- **I:E**: 36
- **O2**: 0.520
- **VT**: 1.70
- **Tinsp**: 18
- **f**: 5
- **PEEP**:
HYBRID MODES OF VENTILATION

SIMV and A/C
HYBRID MODES OF VENTILATION
A/C

<table>
<thead>
<tr>
<th>Control</th>
<th>Trigger</th>
<th>Limit</th>
<th>Target</th>
<th>Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Or</td>
<td>Time</td>
<td>Time</td>
<td>Time</td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>Or Patient</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Time or Patient Triggered Time Cycled Ventilation
Patient Triggered, Flow limited, Volume Cycled Ventilation
**Assisted Mode**  
*(Pressure-Targeted Ventilation)*

- **Flow (L/m)**
- **Pressure (cm H₂O)**
- **Volume (mL)**

---

Patient Triggered, Pressure Limited, Time Cycled Ventilation
**Pressure or Volume-Targeted Ventilation**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Decreases the work of breathing (WOB)</td>
<td>- Alveolar hyperventilation</td>
</tr>
<tr>
<td>- Allows patients to regulate respiratory rate</td>
<td></td>
</tr>
<tr>
<td>- Helps maintain a normal PaCO2</td>
<td></td>
</tr>
</tbody>
</table>
### Hybrid Modes of Ventilation

**SIMV/PS**

<table>
<thead>
<tr>
<th>Breath Type</th>
<th>Control</th>
<th>Trigger</th>
<th>Limit</th>
<th>Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mandatory</td>
<td>Pressure Or Volume</td>
<td>Time Or Patient</td>
<td></td>
<td>Time</td>
</tr>
<tr>
<td>Spontaneous</td>
<td>Pressure</td>
<td>Patient</td>
<td>Pressure</td>
<td>Flow</td>
</tr>
</tbody>
</table>
SIMV
(VOLUME TARGETED VENTILATION)

Pressure (cm H₂O)

Flow (L/m)

Volume (mL)

Time (sec)

Spontaneous Breaths
SIMV + PS
(PRESSURE-TARGETED VENTILATION)

**Pressure (cm H$_2$O)**
- $T_{synch}$
- Set PC Level
- Set PS Level

**Flow (L/m)**
- Time Cycled
- Flow-cycled

**Volume (mL)**

**Time (sec)**
HYBRID MODE VENTILATION: SUPPRESSION
Hybrid Mode Ventilation: Synchronization (SIMV+PSV)

- Time (sec)
- Flow (L/m)
- Pressure (cm H₂O)

**Triggers**:
- M (Mandatory Cycle Time)
- T_{supp} (Triggered window for supported breaths)
- T_{synch} (Triggered window for synchronized breaths)

**Cycles**:
- M
- T_{supp}
- T_{synch}
- M
- T_{synch}
- T_{supp}

**Legend**:
- Green bar: Mandatory Cycle Time
- Pink bar: Triggers for supported and synchronized breaths

**Time (sec)**
SIMV

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintains respiratory muscle strength by avoiding muscle atrophy</td>
<td>When used for weaning, may be done too quickly and cause muscle fatigue</td>
</tr>
<tr>
<td>Decreases mean airway pressure</td>
<td>Mechanical rate and spontaneous rate may asynchronous causing “stacking”</td>
</tr>
<tr>
<td>Facilitates ventilator discontinuation – “weaning”!</td>
<td>• May cause barotrauma or volutrauma</td>
</tr>
</tbody>
</table>
ALL MODES TABLES
## Mandatory Modes of Ventilations

<table>
<thead>
<tr>
<th>Mandatory Breaths</th>
<th>Inspiratory Cycling</th>
<th>Control</th>
<th>Target/Limit</th>
<th>Feedback</th>
<th>Expiratory Cycling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Time</td>
<td>Time</td>
<td>Time</td>
<td>Time</td>
<td>Time</td>
</tr>
<tr>
<td>Volume</td>
<td>Volume</td>
<td>Volume</td>
<td>Pressure-limited</td>
<td>Volume-targeted</td>
<td></td>
</tr>
</tbody>
</table>

- **Inspiratory Cycling**
  - Time: Time
  - Volume: Volume
  - Target/Limit: Pressure-limited
  - Feedback: Intra-breath

- **Expiratory Cycling**
  - Time: Time

### Triggered Breaths

#### Types
- None

### Supported Breaths

#### Control
- None

#### Target
- None

#### Feedback
- None

#### Expiratory Cycling
- None

### Spontaneous Breaths

#### During Mandatory Inspiration
- Not accommodated

#### Otherwise
- Not accommodated

#### Synonyms
- IPPV (Draeger): Controlled Mandatory Ventilation
- Intermittent Mandatory Ventilation
- IPPV (Draeger): trigger off, autoflow off
- IPPV (Draeger): trigger off, autoflow on

#### Accommodated
- Accommodated

#### Not Accommodated
- Not accommodated

#### Intra-breath
- Intra-breath

#### Inter-breath
- Inter-breath
# Triggered Modes of Ventilations

<table>
<thead>
<tr>
<th>Mandatory breaths</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspiratory cycling</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Control</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Target/Limit</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Feedback</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Expiratory cycling</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

## Triggered Breaths

<table>
<thead>
<tr>
<th>Types</th>
<th>Supported breaths</th>
<th>Supported breaths</th>
<th>Supported breaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>Pressure</td>
<td>(Pressure)</td>
<td>(Pressure)</td>
</tr>
<tr>
<td>Target</td>
<td>--</td>
<td>Volume-targeted</td>
<td>Flow and Volume</td>
</tr>
<tr>
<td>Feedback</td>
<td>--</td>
<td>Inter-breath</td>
<td>Intra-breath</td>
</tr>
<tr>
<td>Expiratory Cycling</td>
<td>Flow</td>
<td>Flow</td>
<td>Flow</td>
</tr>
</tbody>
</table>

## Spontaneous Breaths

| During mandatory inspiration | - | - | - |
| Alternatively | - | - | - |

## Synonyms

- Assisted Spontaneous Breathing (Draeger)
- Spontaneous Mode (Hamilton, Puritan Bennet)
- Pressure Support (Maquet)
- Pressure Support Ventilation (Viasys)
- CPAP (Respironics)
- Volume Support (Maquet, Puritan-Bennett)
- Propotional Assist Ventilation, Proportional Pressure Support (Draeger)
- Propotional Assist Ventilation Plus (Puritan-Bennet)
Hybrid Mode: Assist Control

<table>
<thead>
<tr>
<th>Mandatory breaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspiratory cycling</td>
</tr>
<tr>
<td>Control</td>
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<tr>
<td>Target/Limit</td>
</tr>
<tr>
<td>Feedback</td>
</tr>
<tr>
<td>Expiratory cycling</td>
</tr>
</tbody>
</table>

<table>
<thead>
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</tr>
</thead>
<tbody>
<tr>
<td>Types</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Supported Breaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
</tr>
<tr>
<td>Target</td>
</tr>
<tr>
<td>Feedback</td>
</tr>
<tr>
<td>Expiratory Cycling</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spontaneous Breaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>During mandatory inspiration</td>
</tr>
<tr>
<td>Otherwise</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Synonyms</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPPV ASSIST (Draeger)</td>
</tr>
<tr>
<td>Synchronized cCondrolled Mandatory Ventilation (Hamilton)</td>
</tr>
<tr>
<td>Volume Control (Maquet)</td>
</tr>
<tr>
<td>VCV-A/C (Puritan-Bennett, Respironics)</td>
</tr>
<tr>
<td>Volume A/C (Viasys)</td>
</tr>
<tr>
<td>BIPAP ASSIST (Draeger)</td>
</tr>
<tr>
<td>P-CMV (Hamilton)</td>
</tr>
<tr>
<td>Pressure Control (Maquet)</td>
</tr>
<tr>
<td>PCV-A/C (Puritan-Bennett, Respironics)</td>
</tr>
<tr>
<td>Pressure A/C (Viasys)</td>
</tr>
<tr>
<td>Adaptive Pressure Ventilation CMV PRVC (Maquet)</td>
</tr>
<tr>
<td>VC+A/C (Puritan-Bennet)</td>
</tr>
<tr>
<td>PRVC A/C (Viasys)</td>
</tr>
<tr>
<td>IPPV Assist Autoflow (Draeger)</td>
</tr>
</tbody>
</table>
# Hybrid Mode: Synchronized Intermittent Mandatory Ventilation

## Mandatory breaths

<table>
<thead>
<tr>
<th>Control</th>
<th>Volume</th>
<th>Pressure</th>
<th>(Pressure)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target/Limit</td>
<td>-</td>
<td>-</td>
<td>Volume-targeted</td>
</tr>
<tr>
<td>Feedback</td>
<td>-</td>
<td>-</td>
<td>Inter-breath</td>
</tr>
</tbody>
</table>

## Triggered Breaths

<table>
<thead>
<tr>
<th>Types</th>
<th>Mandatory and supported pattern</th>
<th>Mandatory and supported pattern</th>
<th>Mandatory and supported pattern</th>
</tr>
</thead>
</table>

## Supported Breaths

<table>
<thead>
<tr>
<th>Control</th>
<th>Pressure</th>
<th>Pressure</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Feedback</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

## Spontaneous Breaths

<table>
<thead>
<tr>
<th>During mandatory inspiration</th>
<th>Not accommodated</th>
<th>Accommodated</th>
<th>Accommodated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Otherwise</td>
<td>Only if support is off</td>
<td>Only if support is off</td>
<td>Only if support is off</td>
</tr>
</tbody>
</table>

## Synonyms

| SIMV (Draeger, Hamilton) | SIMV (VC)+PS (Maquet) | VCV-SIMV (Puritan-Bennett, Respironics) | Volume SIMV (Viasys) | P-SIMV (Hamilton) | SIMV(PC)+PS (Maquet) | PCV-SIMV (Puritan-Bennett, Respironics) | Pressure SIMV (Viasys) | SIMV+Autoflow | Adaptive Pressure Ventilation SIMV (Hamilton) | SIMV (PRVC)+PS (Puritan-Bennett) | PRVC SIMV (Viasys) |
## Hybrid Mode: Bi-Level Ventilation

<table>
<thead>
<tr>
<th></th>
<th>Mandatory breaths</th>
<th>Triggered Breaths</th>
<th>Supported Breaths</th>
<th>Spontaneous Breaths</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inspiratory cycling</strong></td>
<td>Time or trigger</td>
<td>Time or trigger</td>
<td>Time or trigger</td>
<td>Time or trigger</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>Pressure</td>
<td>Pressure</td>
<td>Pressure</td>
<td>Pressure</td>
</tr>
<tr>
<td><strong>Target/Limit</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Feedback</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Expiration cycling</strong></td>
<td>Time or trigger</td>
<td>Time or trigger</td>
<td>Time or trigger</td>
<td>Time or trigger</td>
</tr>
</tbody>
</table>

### Triggered Breaths
- **Interaction**: Mandatory and supported
- **Supported Breaths**
- **Control**
- **Target**
- **Feedback**
- **Expiration Cycling**: Flow

### Spontaneous Breaths
- **During mandatory inspiration**: Accommodated
- **Otherwise**: Triggers support
- **Synonyms**
  - **BIPAP (Draeger)**
  - **DuoPAP/APRV (Hamilton)**
  - **BiLevel (Puritan-Bennett)**
  - **APRV/Bi-phasic (Viasys)**
  - **Bi-vent (Maquet)**

Triggers support to PEEP$+P_{\text{support}}$ (Hamilton DuoPAP)
Triggers support to PRES$\text{HIGH} + \text{PSV}$ if $T_{\text{H}}$ P$\text{SV}$ is activated
Triggers support to PSV above $P_{\text{HIGH}}$
Triggers support to PSV above PEEP
THANK YOU