Mechanical Ventilation
Waveforms and Modes

ISRC 43rd Annual Conference

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### Common Initial Ventilator Settings

**(Volume Controlled)**

<table>
<thead>
<tr>
<th>Mode</th>
<th>AC or SIMV</th>
</tr>
</thead>
<tbody>
<tr>
<td>RR</td>
<td>12 - 14/min</td>
</tr>
<tr>
<td>$V_T$</td>
<td>7 - 8 ml/kg</td>
</tr>
<tr>
<td>FiO$_2$</td>
<td>1.0</td>
</tr>
<tr>
<td>PEEP</td>
<td>5 cmH$_2$O</td>
</tr>
<tr>
<td>Vi</td>
<td>60 L/m cont</td>
</tr>
<tr>
<td></td>
<td>80 L/m decel</td>
</tr>
</tbody>
</table>

- ABGs, airway pressures and patient-ventilator synchrony guide subsequent changes.

The Mechanical Breath
Constant Inspiratory Flow

- Peak inspiratory flow rate
  PIFR

- Beginning of inspiration
  exhalation valve closes

- Beginning of expiration
  exhalation valve opens

- Inspr. time $T_I$

- Expiratory Time $T_E$

- Resp cycle time $RCT$

- Peak expiratory Flow
Flow-Pressure-Volume Relationships

- Flow (l/m)
- Pressure (cmH$_2$O)
- Volume (mL)

Time (s)

- 0
- 0.5
- 3
Flow - Pressure - Volume Relationships

Flow (l/min)
Pressure cmH₂O
Volume mL

Time (s)

RCT = 3 s
RR = 20/min
Vₜ = 500 ml
I:E = 1:5
Controlled Mode
(Volume Controlled)

Time triggered, Flow limited, Volume cycled

Set Flow Rate and Pattern

Flow L/m

Pressure cm H$_2$O

Peak pressure dependent on $C_{RS}$ & $R_{aw}$

Set PEEP

Volume mL

Set $V_T$

Time (sec)

Set RR
Assist Control
(AC, Volume Controlled)

Patient/time triggered, Flow limited, Volume cycled

Flow
L/m

Pressure
cm H₂O

Volume
mL

Set flow and pattern

Ppk: depends on Peep, V_t, C_Rs, & R_aw

Set PEEP

Set RR and V_t

Time (sec)
Synchronized Intermittent Mandatory Ventilation: a Mixed Mode (SIMV, Volume Controlled)
Synchronized Intermittent Mandatory Ventilation (SIMV)

Example 1:
- PIM: patient-initiated mandatory breath
- PIM delivered within Tm

Example 2:
- PIM not delivered within Tm
- VIM: ventilator-initiated mandatory breath
SIMV + PSV (Mixed Mode)

- **Flow** (L/min)
- **Pressure** (cm H$_2$O)
- **Volume** (ml)

PS breath
Flow-Pressure Relationships

Square pressure requires decelerating flow
Constant vs Decelerating Flow
(AC, Volume Controlled)

Time/Pt triggered, Flow limited, Volume cycled

Set flow rate and pattern

Peak pressure is not set
PEEP is set

Set RR and $V_T$

Flow (L/min)
Pressure (cm H$_2$O)
Volume (ml)

Time (sec)
Pressure Support Ventilation (PSV)

Patient triggered, Pressure limited, Flow cycled

Flow cycling

Flow L/m

Pressure cm H₂O

Volume mL

Time (sec)

Flow cycling

PS level

PEEP
Pressure Regulated Volume Controlled Ventilation (VC Plus) (AC, Volume Controlled)

- **Pressure** (cm H$_2$O)
  - Vt is set, not pressure
  - PEEP is set

- **Flow** (L/min)
  - Ti is set, not flow

- **Volume** (ml)
  - (RR is set)

- **Time** (sec)
Pressure Regulated Volume Controlled Ventilation (VC Plus)
Pressure-Controlled Ventilation (AC, Pressure Controlled)

Time/pt triggered, Pressure limited, Time cycled

Ti is set, not flow

PEEP and pressure above PEEP are set

Dependent on Raw, Cstrs and vent settings

Flow (L/min)
Pressure (cm H₂O)
Volume (ml)

Time (sec) (RR is set)
Volume-Controlled Ventilation

(AC, Volume Controlled/Decelerating flow)

Time/Pt triggered, Flow limited, Volume cycled

Flow and flow pattern is set

Pressure is not set

Tidal volume is set

Time (sec)

RR is set
Biphasic (Bilevel) (Pressure Controlled Ventilation)

Time/Pt Triggered, Pressure Limited, Flow/Time Cycled

Flow (L/min)

Pressure (cm H₂O)

Volume (ml)

Time (sec)
Biphasic (Bilevel)

Figure 1. Bilevel mode

Figure 2. Bilevel with pressure support
Airway Pressure Release Ventilation
APRV

[Graph showing airway pressure and spontaneous breaths]
Name that Mode
Name that Mode
What Happens When Respiratory System Mechanics Change?

When airway pressures, respiratory rate and inspiratory time are matched, changing modes is often seamless—such that pressure, flow and volume waveforms may look almost identical.

However, appropriate management presupposes an understanding of how the ventilator will respond to changes in patient mechanics.
Selected Goals

- Optimize gas exchange
- Achieve patient-machine synchrony
- Decrease but not eliminate WOB
- Mitigate ventilator induced lung injury
Select Studies Comparing Modes

• SIMV vs AC in ARF: no difference in hemodynamic, metabolic, ventilatory or oxygenation variables

• AC vs SIMV vs SIMV/PSV: SIMV/PSV increased minute ventilation and ventilatory equivalent compared to other modes

• SIMV-PSV vs A/C: no difference in clinical outcomes, despite treatment-allocation bias that would have favored SIMV-PSV

• APRV vs AC: no difference in mortality

1 Groeger JS, Crit Care Med 1989; 17: 607:
2 Shelledy DC, Heart and Lung 1995; 24: 67
3 Ortiz G, Chest 2010; 137: 1265
4 Gonzalez M, Intensive Care Med 2010; 36: 817
Evolution of MV 1998 -2004

- Noninvasive ventilation increased (11.1 vs. 4.4%, P < 0.001).

- In ARDS, tidal volumes decreased (7.4 vs. 9.1 ml/kg, P < 0.001) and positive end-expiratory pressure levels increased slightly (8.7 vs. 7.7 cm H(2)O, P = 0.02).

- More patients were successfully extubated after their first attempt of spontaneous breathing (77 vs. 62%, P < 0.001).

- Use of SIMV fell dramatically (1.6 vs. 11%, P < 0.001).

Esteban A, AJRCCM 2008; 177: 170
Pressure Waveform Analysis
Constant Flow

Peak Inspiratory Pressure (PIP)

Time (sec)

\[ P_{aw} \text{ (cm H}_2\text{O)} \]
**CONSTANT FLOW**

- **Begin Inspiration**
- **Begin Expiration**

- **Paw** (cm H$_2$O)
- **Time (sec)**

**Inflation Hold (seconds)**
- Exhalation Valve Opens

**PIP**

**Pplat**

**35 PIP**

**25 Pplat**

**5 PEEP**

- Eg, square flow 60 lpm, Vt 600
- Raw = 10 cmH$_2$O/L/s
- Cstrs = 30 ml/cmH$_2$O
Mechanics

Airway Resistance (Raw)

- Square flow 60 L/min (1L/s)
- PIP - Pplat cmH\(_2\)O L/sec
- Normal < 15 cmH\(_2\)O/L/sec
- Causes of increased Raw:
  - Occluded ETT
  - Secretions
  - Bronchospasm

Static Compliance of the Respiratory System (Cstrs)

- C = \( \Delta V / \Delta P \)
- Cstrs = \( (Vt)/(Pplat - PEEP) \)
- Normal 60 - 80 ml/cmH\(_2\)O
- Causes of low compliance
  - Pulmonary edema
  - Pleural effusion
  - Pneumothorax
  - Right mainstem intubation
  - Tense abdomen
  - Hyperinflation
Normal vs Obstruction

Flow (L/min)

Time (sec)

Normal

Expiratory Obstruction
Normal vs. Expiratory Airflow Obstruction
Auto-PEEP Determination

$P_{aw}$ (cm H$_2$O)

Inspiration

Expiration

Expiratory hold

Time (sec)

Auto PEEP

Total PEEP

Set PEEP
Response to Bronchodilator

Before

After

Time (sec)

Paw (cm H₂O)

PIP

Pplat

PIP

Pplat
Response to Bronchodilator

Before

PEFR

Long $T_E$

Higher PEFR

After

Time (sec)

Shorter $T_E$
Inadequate Inspiratory Flow

Adequate Flow

Inadequate Flow

\[ P_{aw} \text{ (cm H}_2\text{O)} \]

Time (sec)
Inadequate Inspiratory Flow

Active Inspiration or Asynchrony

Patient’s effort

Flow (L/min)

Time (SEC)

Normal
Abnormal