Course no:  Course 3
Title:  “RESPIRATORY PHYSIOLOGY, PHYSICS AND PATHOLOGY IN RELATION TO ANAESTHESIA AND INTENSIVE CARE”
Sub-category:  Ventilatory Support
Topic:  Modes of Ventilation
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Disclosure

• I do not have relevant financial interest, arrangement or affiliation that would constitute a conflict of interest.
Respiratory System

Basically is a gas exchanger with a pump
Mechanical Ventilation

• Designed to replace the “pump part” of respiratory system
• Not to support the “gas exchanger part”
• It is through the adjustments of the “pump” part that we try to help “gas exchanger” when it is diseased
• Hence the refinements and development of newer modes
Objective of Ventilation

• Decrease Work of Breathing

• Reverse Hypoxaemia

• Reverse Respiratory Acidosis
Before starting Ventilatory Support

Ask yourself

Can this patient be ventilated Non Invasively??
Non Invasive Mechanical Ventilation (NIMV)

Requirements:

- At least some residual ability of spontaneous breathing (need for full mechanical support is absolute contra-indication for non-invasive approach)
- No estimated need of high levels of positive pressure
- No active facial trauma, skull based fracture or recent surgery on digestive tract
NIMV Advantages

• Low risk if there is temporary disconnection of ventilator

• Haemodynamic stability

• Good co-operation of the patient

Lotti GA. Patient – Centered Acute Care Training (PACT) Module of Skills and Techniques – Mechanical ventilation, ed by: Graham Ramsay 2006: 2-10
Well fitting face mask with harness in NIMV
Spontaneous Breath

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

Time (sec)
PPV Breath

Variables

• **Trigger**
  – What initiates the breath?

• **Limit (Target)**
  – What regulates gas flow during the breath?

• **Cycling**
  – What terminates the breath?
Trigger Variables

- Flow – Assisted Breath
- Pressure – Assisted Breath
- Time – Controlled Breath
- Others:
  - Volume, Shape Signal, Neural
Target Variables

Control the gas delivery during the breath

• **Flow** – Volume Controlled Modes

• **Pressure** – Pressure Controlled Modes
Cycle Variables

Cycling from inspiration to expiration

• Volume – Volume Control
• Time – Pressure Control
• Flow – Pressure Support
• Pressure – (Safety Cycling Variable)
Conventional Primary Modes

- Completely Controlled: VCV, PCV, PC-IRV
- Partially Controlled: ACV, VC-SIMV, PC-SIMV
- Supported Spontaneous: PSV, CPAP
Conventional Primary Modes
Completely Controlled Ventilation
Volume Controlled Ventilation (VCV)  
(Volume Targeted Ventilation)

- Controlled inspiratory flow, delivered
  - during set inspiratory time
  - according to set flow pattern
  - to achieve a set tidal volume

- The only mode that guarantees minimum minute ventilation.

- This could be at the cost of barotrauma or volutrauma.
VCV

Time triggered, Flow limited, Volume cycled Ventilation

Preset Peak Flow

Dependent on $C_L$ & $R_{aw}$

Flow
L/m

Pressure
cm H$_2$O

Volume
mL

Preset $V_T$

Volume Cycling

Time (sec)
Pressure Controlled ventilation (PCV)

- Ventilator applies a positive pressure wave above the baseline pressure.

- There is fast increase in pressure to the user set level that is maintained throughout the inspiration.

- Only PCV can guarantee limitation of pressure applied by ventilator.
Pressure Controlled (PCV)
(Pressure-Targeted Ventilation)

Time Triggered, Pressure Limited, Time Cycled Ventilation

Flow
(L/min)

Pressure
(cm H₂O)

Volume
(ml)

Time (sec)

Set PC level

Time-Cycled
Opening Pressures in Different areas of Lungs

- **Alveolar Collapse (Reabsorption)**: 40-60 cmH₂O
- **Small Airway Collapse**: 10-20 cmH₂O
- **Inflated**: 0 cmH₂O
- **Consolidation**: \(\infty\) cmH₂O

Conventional Primary Modes Completely Controlled Ventilation
Volume Controlled Ventilation
Pressure Controlled Ventilation
PC-IRV

- Pressure control mode with I:E ratio > 1:1
- Operator sets an inflating pressure, inspiratory time and frequency
- Set inflation pressure is quickly achieved and maintained throughout inspiratory cycle
- Requires heavy sedation and muscle relaxation
- Ensures a more homogeneous ventilation and keeps collapsible alveoli open for a longer time
PCV vs PC-IRV

Conventional Primary Modes
Completely Controlled Ventilation
Conventional Primary Modes
Partially Controlled Ventilation
Assist Control Mode (ACV)

Set tidal volume delivered:
- whenever triggered by the patient
  or
- Independently, if such an effort does not occur within a preselected time
**ACV**

(Volume-Targeted Ventilation)

Patient triggered, Flow limited, Volume cycled Ventilation

![Graph showing Flow (L/m), Pressure (cm H₂O), and Volume (mL) over Time (sec).]
ACV
(Pressure-Targeted Ventilation)

Patient Triggered, Pressure Limited, Time Cycled Ventilation
SIMV

- Provide graded levels of assistance
- Physician sets the number of mandatory breaths of fixed volume to be delivered by the ventilator; between these breaths, the patient can breathe spontaneously
- Decrease in the work of breathing may be much less than desired, because the patient feels difficulty in adopting to the intermittent nature
- Could be “Volume” or “Pressure Targeted”
SIMV
(Volume - Targeted Ventilation)

Conventional Primary Modes
Partially Controlled Ventilation

Flow
L/m

Pressure
cm H₂O

Volume
mL

Spontaneous Breaths
SIMV
(Pressure-Targeted Ventilation)

Conventional Primary Modes
Partially Controlled Ventilation

Flow (L/min)
Pressure (cm H₂O)
Volume (ml)
Time (sec)
Set PC level
Spontaneous Breath
SIMV+PS
(Volume-Targeted Ventilation)

Conventional Primary Modes
Partially Controlled Ventilation

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

Flow-cycled
Set PS level
PS Breath
SIMV + PS
(Pressure-Targeted Ventilation)

Conventional Primary Modes
Partially Controlled Ventilation

Flow (L/min)

Pressure (cm H₂O)

Volume (ml)

Time (sec)

Time-Cycled

Flow-Cycled

Set PC level

Set PS level

PS Breath
SIMV+PS+ CPAP (Volume-Targeted Ventilation)

Conventional Primary Modes
Partially Controlled Ventilation

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

Set PS level
CPAP level

Time (sec)
SIMV + PS + CPAP
(Pressure-Targeted Ventilation)
ACV vs SIMV

Conventional Primary Modes
Partially Controlled Ventilation

Assisted Mode
(Volume-Targeted Ventilation)

SIMV
(Volume-Targeted Ventilation)
Conventional Primary Modes

Supported Spontaneous Ventilation
CPAP

Conventional Primary Modes
Supported Spontaneous Ventilation

Flow
L/m

Pressure
cm H$_2$O

Volume
mL

Time (sec)
• A pressure preset mode in which each breath is patient triggered and supported
• Each inspiration is supported by a fixed positive pressure set by the physician
• If the patient increases inspiratory effort amount of support will remain the same
• Only applied to spontaneous breaths
• is flow cycled; cycled off when the patient's inspiratory flow declines to a value determined by the manufacturer of the ventilator

Pressure support has a:

• Set pressure (pressure support added to the CPAP/PEEP)

• Variable volume - determined by the resistance, compliance, inspiratory effort and level of pressure support

• Variable flow rate determined by the resistance, compliance, inspiratory effort and level of pressure support

• Variable inspiratory time

• Basically designed to decrease work of breathing

• Can be used in addition to SIMV
Patient Triggered, Flow Cycled, Pressure limited Mode

- Flow Cycling
- Set PS level

Conventional Primary Modes
Supported Spontaneous Ventilation

Flow (L/m)
Pressure (cm H₂O)
Volume (mL)
Time (sec)
Flow Cycle Criteria and Brand Names on Some Common Mechanical Ventilators

<table>
<thead>
<tr>
<th>Ventilator</th>
<th>Flow Cycling Range (%)</th>
<th>Brand Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE Engström Carestation</td>
<td>5–50</td>
<td>EndFlow</td>
</tr>
<tr>
<td>Newport E500</td>
<td>5–55</td>
<td>Expiratory Threshold</td>
</tr>
<tr>
<td>Puritan Bennett 840</td>
<td>1–45</td>
<td>Esens</td>
</tr>
<tr>
<td>Respironics V200</td>
<td>10–80</td>
<td>Ecycle</td>
</tr>
<tr>
<td>Maquet Servo-i</td>
<td>10–70</td>
<td>Inspiratory Cycle Off</td>
</tr>
<tr>
<td>Hamilton G5</td>
<td>5–70</td>
<td>Expiratory Trigger Sensitivity</td>
</tr>
<tr>
<td>Dräger Evita XL</td>
<td>25</td>
<td>(none)</td>
</tr>
<tr>
<td>Carefusion Avea</td>
<td>5–45</td>
<td>PSV Cycle</td>
</tr>
</tbody>
</table>

Michael A Gentile Respir Care 2011;56:52-60
Effect of Respiratory Mechanics on Cycling of Pressure Support from Inhalation to Exhalation

Michael A Gentile Respir Care 2011;56:52-60
Disadvantages:

- Variable Vt and MV
- No backup if patient becomes apnoeic
- Continuous nebulization therapy is difficult during PSV
- Forced exhalation if ventilator does not end inspiration properly resulting and hence, an increased work-of-breathing
- Can be combined with CPAP
Biphasic Modes

- BiPAP or DuoPAP
- APRV
- BiLevel
- HFV
BiPAP

- Circuit switches between a high and low airway pressures set by physician
- Pressure-controlled ventilation
- Allows unrestricted spontaneous breathing throughout the respiratory cycle
- I:E ratio and the ventilatory frequency can be adjusted
Airway Pressure Release Ventilation (APRV)

• APRV is
  – Two levels of CPAP are set (P1 and P2)
  – Baseline airway pressure is upper CPAP level
  – Intermittently releases to a lower level
  – Using a time-controlled release valve

• CPAP and lung volumes are re-established when the release valve closes

• Pt is allowed to breathe spontaneously

• **APRV always** implies a grossly reverse I:E ratio
Benefits of APRV

- Preservation of spontaneous breathing
- Patient comfort
- Spontaneous breathing throughout the cycle
- Little work of breathing
- This translates in less barotrauma; reduction in circulatory compromise; and a better matching of pulmonary ventilation and perfusion
APRV Settings

• **Start with the “respiratory rate”:** $60/\text{RR}$ gives you your cycle time. Example RR 15 gives cycle time of 4 seconds

• **Set T1 and T2:** Example I:E ratio 4:1 results in $T1$ of 3.2 seconds and $T2$ of 0.8 seconds

• **Set P1 and P2:** Set P2 at the PEEP set on previous mode of ventilation. Set P1 to appropriate TV
Pressure, Volume and Flow /Time Graphs of APRV

APRV

Pressure (cm H₂O)

- CPAP phase
- Spontaneous breath
- Release phase
- Time

Volume (ml)

- Spontaneous breath
- Time

Flow (L/min)

- Spontaneous breath
- Time
APRV: Indications

- ARDS/ALI
- Severe CHF
- Severe hypoxia
- Hemodynamically unstable patients
APRV: Contra-indications

- Obstructive lung disease
- High minute ventilation requirement
  - Dynamic hyperinflation
  - High alveolar pressures
  - Barotrauma
BiLevel

- BiLevel is a combination of APRV and BIPAP
- Mixes spontaneous and mandatory breath types
- The mandatory breaths are pressure controlled and the spontaneous breaths can be pressure supported
- Ventilator cycling between the two pressure levels can be synchronized with the patient
Bi Level vs APRV

• Bi-level is just a tad different than APRV, in that the low peep used in bi-level is generally not zero, and in APRV the ventilator uses the release time as an auto-peep generator.
• Different Ventilator
• Frequency 2.5 to 15 Hz
• Tidal Volume 0.5 – 5 ml/kg
• Can be of 3 types
  – HFPPV – RR 60 - 150
  – HFJV – RR 150 - 600
  – HFO – RR 600 - 3000
DUAL CONTROL MODES

- Partially Closed Loop Ventilation
- Completely Closed Loop Ventilation
DUAL CONTROL
PARTIAL CLV

Breath to Breath Control
PRVC, VPS,

Within Breath Control
VAPS, PA
Closed Loop Ventilation

• Def: When input from patient controls the output from the ventilator
• Simple: One input --- One output e.g. ACV
• Complex: Multiple Inputs ---- Multiple Outputs

Crit Care Clin. 2007 Apr;23(2):223-40
Closed Loop Ventilation

Dual Control Modes

CLV

ASV

PAV

Auto mode

SAVI

Smart Care

NAVA
Pressure Regulated Volume Control (PRVC)

• Siemens 300a ventilator

• Used to achieve volume support while keeping PIP at their lowest possible level

• Done by altering peak flow and inspiratory time in response to changing airway resistance and compliance
PRVC

• First breath is volume controlled

• Measured plateau pressure used as pressure level for next breath

• If the measured tidal volume increases above the preset, the pressure level decreases in steps of maximum 3 cm H$_2$O between consecutive breaths until the preset tidal volume is delivered

• Maximum available pressure level is 5 cm H$_2$O below a preset upper pressure limit
Pressure, Volume, Flow Time Graph in PRVC Mode

Dual Control Modes
Partially Closed Loop
Breath to Breath Control
Other modes in this Group

Other Examples of Breath to Breath Dual-Control Ventilation:

- Volume Support – Siemens 300 (VSV)
- Variable Pressure Support (VPS)
- Variable Pressure Control (VPC) – Cardiopulmonary Corp Venturi
- VCV+ : Puritan Bennet 840
Dual Control Modes

Partially Closed Loop Ventilation

Within Breath Control
Volume Assured Pressure Support (VAPS)

• Bird 8400 STi and T Bird ventilators
• Switches between VC and PC within a breath
• Clinician has to set tidal volume, pressure limit and flow limit
• If the delivered Vt is < set Vt then PS is increased within the same breath
VAPS

- The moment breath is initiated, ventilator compares output with target, changing to volume support, if needed.
- If patient’s effort is weak, or if impedance changes, the breath converts to volume control.
Set flow limit

Set tidal volume cycle threshold

Set pressure limit overridden

Tidal volume not met

Inspiratory flow greater than set flow

Flow cycle

Set tidal volume met

Inspiratory flow equals set flow

Switch from Pressure control to Volume/flow control

Pressure limit overridden

Flow limit

Volume

Flow

P_{aw}

cmH_2O

Volume

Flow

L/min

L
SAVI

• Synchronised Assistance to Ventilation in Infants (SAVI)
• Synchronization is accomplished by modified thoracic impedance technology using standard neonatal cardiorespiratory monitors with the output of the ventilation
• Sechrist Ventilator
Smart Care

- Used by Drager Ventilators
- Conventional pressure support ventilation
- Before starting a session the clinician enters a menu to tailor the “Zone of Respiratory Comfort” defined by breathing frequency, tidal volume and et CO2
- The level of pressure support is adjusted to maintain tidal volume (\(V_t\)) above, and etCO2 below, certain values, adjusting to patient’s metabolic needs
Proportional Assist Ventilation (PAV)

- PAV provides dynamic inspiratory pressure assistance in linear proportion to patient-generated volume and flow
- Ventilator changes support according to patient effort, to always give a set proportion of the breath
- Clinician sets % of WOB
- Puritan Bennet 840
- Ventilator guarantees the percentage of work regardless of changes in pulmonary compliance and resistance
PVF – Time Graphs for PAV

**PAV**
- Increased effort
- Increased pressure

**Decreased effort**
- Decreased pressure

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

**Time**
Dual Control Modes
Completely Closed Loop Ventilation
DUAL CONTROL
COMPLETE CLV

Breath to Breath Control

Automode, ASV
Automode

- Siemens 300A
- Combines PRVC with volume support
- Alters between time cycled and flow cycled breaths depending on the patient effort
- 2 consecutive breaths that trigger mechanical breaths
  - Automode switches to volume support
  - All breaths become patient triggered, pressure limited and flow cycled
Automode

• If the patient stops breathing for a pre-determined period of time (5sec for neonate; 8sec for pediatric; 12sec for adult)

• Ventilator automatically switches back to a control mode

Eur J Cardiothorac Surg 2006;29:957-963
Adaptive Support Ventilation (ASV)

- Used by Galileo, Raphel, G5 and C3 ventilators
- Closed – loop controlled mode that switches from PCV to PC-SIMV to PSV modes
- Pressure targeted, time-cycled mandatory breaths and pressure targeted, flow-cycled patient controlled breaths
- Calculates the expiratory time constant in order to guarantee sufficient expiratory time and thus minimize air trapping
ASV

• Clinician enters IBW and % of MV
• As spontaneous breathing increases, number of mandatory breaths will decrease and the PS level will increase until $V_t = \text{alveolar volume} + 2.2\text{mL/kg of Vd}$
• Ensures early tracheal extubation
• Earlier extubation when compared to PRVC and Automode

Anesth Analg. 2003 Dec;97(6):1743-50
Anesthesiology. 2008 Jul;109(1):81-7
INTELLiVENT ASV

- Completely Closed Loop Ventilation
- Caters for passive and spontaneously breathing adult and pediatric patients
- Automatically controls ventilator settings based on the targets for ventilation and oxygenation set by the clinician and on physiologic input from the patient
- Clinician sets targets for PetCO$_2$ and SpO$_2$ for the patient
- Automatically applies lung-protective strategies to minimize complications from AutoPEEP and volutrauma/barotrauma
- Encourages patient to breathe spontaneously
- Provides an automated weaning protocol
NOVEL MODES

NAVA

Liquid Ventilation
NAVA

• Neurally Adjusted Ventilator Assist
• Announced by Maquet at MEDICA 2006 on Servo
• Mechanical Ventilation is based on patient’s neural respiratory output
• Bipolar electrodes attached to a nasogastric tube are positioned in the esophagus at the level of and perpendicular to the crura of the diaphragm

NAVA- Concept

• Signals from respiratory control center in the brain are transmitted through the phrenic nerve to the diaphragm, where a catheter captures the electrical activity (Edi) and feeds it to the ventilator.

• The ventilator responds by providing the requested level of support to the patient.

• As the ventilator and diaphragm work with the same signal, the coupling between the two is virtually instantaneous.

Partial Liquid Ventilation

Benefits:

- Improvement of gas exchange
- Washing out of debris
- Lung recruitment
- Surfactant like effect
- Mitigation of barotrauma / volutrauma
- Mitigation of oxygen toxicity
- Reduction of inflammation
- Less mechanical damage
Conclusion

• There are more than one ways to do a correct thing
• Whole medicine is full of controversies
• Use the mode you are most comfortable with
• Know the dynamics of the mode you are using
• “Do no harm”
Thank You