Selecting and Applying Modes of Mechanical Ventilation in Neonates

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Disclaimer

- All views expressed are my own opinion and not necessarily those of the Cleveland Clinic.
Disclosure

• I have affiliations with, special interests, or have conducted business with the following companies that in context with this presentation might possibly constitute a real or perceived conflict of interest: :
  – Breathe Technologies
  – CareFusion
  – Covidien
  – Dräger
  – Hamilton
  – IngMar
  – Philips
1977 – 3 Modes!

- Assist
- Control
- Assist/Control

Bourns LS 104-150
2014

174 Unique Mode Names!!
The Problem is Even Bigger

• Many modes are not specifically named
  – Mode “features” may be activated that change mode
  – Example: “AutoFlow” feature changes volume control to pressure control with adaptive targeting

• About 300 unique names of modes
  – Using manufacturers’ terminology

• Represent about 50 unique mode categories
  – Based on 4 level taxonomy

• Result
  – high level of redundancy
  – need to discriminate among modes for optimum care
Part 1:
How Do We Identify Modes
A Taxonomy for Mechanical Ventilation: 10 Fundamental Maxims

Robert L Chatburn MHHS RRT-NPS FAARC, Mohamad El Khatib PhD MD RRT FAARC, and Eduardo Mireles-Cabodevila MD

Introduction
What Is a Mode of Mechanical Ventilation?
The 10 Maxims
Application of the Taxonomy
Discussion
  The Problem of Growing Complexity
  The Problem of Identifying Unique Modes
  The Problem of Teaching Mechanical Ventilation
  The Problem of Implementation
Conclusions

Chatburn et al. Respir Care 2014;59(11)
Step 1: Determine the Control Variable

• **Volume Control**
  – Both tidal volume and inspiratory flow are preset
    ▫ *Example: Volume Assist/Control*

• **Pressure Control**
  – Inspiratory pressure preset or proportional to effort
    ▫ *Examples: APRV, NAVA*

• **Time Control**
  – Only inspiratory and expiratory times preset
    ▫ *Example: HFO*
Step 2: Determine the Breath Sequence

• All breaths are spontaneous
  – Continuous Spontaneous Ventilation (CSV)

• Spontaneous breaths are possible between mandatory breaths
  – Intermittent Mandatory Ventilation (IMV)

• Spontaneous breaths are not possible between mandatory breaths
  – Continuous Mandatory Ventilation (CMV)
Step 3: Determine the Targeting Schemes

• Definition of target
  – A predetermined goal of ventilator output

• Within-breath targets
  – Parameters of pressure, volume, flow waveforms
    ▪ Examples: tidal volume, peak flow, inspiratory pressure

• Between-breath targets
  – Modify the within-breath targets and/or the overall ventilatory pattern
  – Examples:
    ▪ Tidal volume for automatic adjustment of PIP
    ▪ Minute ventilation, $P_{ET}CO_2$ or $SaO_2$
Defining the Targeting Schemes

1. **Set-point (s)** – all parameters are operator pre-set
2. **Dual (d)** – ventilator switches between VC and PC
3. **Bio-variable (b)** – ventilator randomly changes target
4. **Servo (r)** – inspiratory pressure proportional to effort
5. **Adaptive (a)** – ventilator adjusts target with changing patient condition
6. **Optimal (o)** – ventilator adjusts target to maximize or minimize some desired parameter
7. **Intelligent (i)** – ventilator adjusts target using artificial intelligence tools
Primary vs Secondary Targeting Scheme

• The “primary” breath targeting scheme refers to the mandatory breaths in CMV and IMV
  – Example: Pressure Control, primary targeting scheme is setpoint and there is no secondary targeting scheme

• If there are no mandatory breaths, then the primary breath must refer to the spontaneous breaths, as in CSV
  – Example: CPAP with Automatic Tube Compensation, primary targeting scheme is servo and there is no secondary targeting scheme

• The “secondary” breaths are the spontaneous breaths in IMV. This is the only breath sequence that has 2 kinds of breaths, ie, both mandatory and spontaneous.
  – Example: SIMV, primary targeting scheme is setpoint, secondary targeting scheme is also setpoint
## Example Mode Classification Scheme

<table>
<thead>
<tr>
<th>Order</th>
<th>Family</th>
<th>Genus</th>
<th>Species</th>
<th>Example Mode Names</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CMV</td>
<td>Set-point</td>
<td>NA</td>
<td>Assist/Control</td>
</tr>
<tr>
<td>Volume Control</td>
<td>Dual</td>
<td>NA</td>
<td>Continuous Mandatory Ventilation with Pressure Limited</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IMV</td>
<td>Set-point</td>
<td>Set-point</td>
<td>Synchronized Intermittent Mandatory Ventilation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dual</td>
<td>Set-point</td>
<td>Synchronized Intermittent Mandatory Ventilation with Pressure Limited</td>
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<tr>
<td></td>
<td></td>
<td>Adaptive</td>
<td>Set-point</td>
<td>Mandatory Minute Ventilation</td>
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<td>CMV</td>
<td>Set-point</td>
<td>NA</td>
<td>Pressure Control</td>
</tr>
<tr>
<td>Pressure Control</td>
<td>Adaptive</td>
<td>NA</td>
<td>Continuous Mandatory Ventilation with AutoFlow</td>
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<tr>
<td></td>
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<td>Set-point</td>
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<td>BiLevel</td>
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<td></td>
<td></td>
<td>Dual</td>
<td>Set-point</td>
<td>Volume Assured Pressure Support</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adaptive</td>
<td>Adaptive</td>
<td>Volume Control Plus Synchronized Intermittent Mandatory Ventilation</td>
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<tr>
<td></td>
<td></td>
<td>Optimal</td>
<td>Optimal</td>
<td>Adaptive Support Ventilation</td>
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<tr>
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<td>Servo</td>
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<td>Proportional Assist Ventilation</td>
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<td>Adaptive</td>
<td>NA</td>
<td>Volume Support</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intelligent</td>
<td>NA</td>
<td>SmartCare</td>
</tr>
</tbody>
</table>
Ventilating the Neonate
Targeting Schemes for Neonates

1. **Set-point (s)** – all parameters are operator pre-set
   - A/C Volume or Pressure
   - SIMV Volume or Pressure
   - Pressure Support
   - CPAP

2. **Servo (r)** – inspiratory pressure proportional to effort
   - Proportional Assist Ventilation (PAV)
   - Neurally Adjusted Ventilatory Assist (NAVA)
Targeting Schemes for Neonates

3. **Adaptive (a)** – ventilator automatically adjusts inspiratory pressure to achieve set tidal volume
   - Volume Guarantee
   - Pressure Regulated Volume Control
   - Volume Assured Pressure Support
   - CMV with AutoFlow
   - Volume Control Plus
Confusion in the Peds Literature

• **Words use to indicate volume control**
  - Volume targeted
  - Volume limited
  - Volume preset
  - Volume control

• **Words use to indicate pressure control**
  - Pressure targeted
  - Pressure limited
  - Pressure preset
  - Pressure control
Confusion in the Peds Literature

• “Assist/Control” and “SIMV” mean (usually)
  – Inspiration is pressure controlled

• “Volume Targeted” can mean
  – Actual volume control
  – Pressure control with adaptive targeting
What the Words Mean

• Pressure Control means predetermined:
  – Inspiratory pressure
    ▫ Constant or proportional to effort
  – Inspiratory time
What the Words Mean

• **Volume Control** means predetermined:
  – Tidal volume
  – Inspiratory flow

• **Volume Guarantee** means:
  – Tidal volume preset (flow depends on mechanics)
  – Inspiratory pressure automatically adjusted

• **Volume Target** means:
  – Volume control
  – Volume guarantee
# 14 Modes on Dräger VN 500

No volume control modes!

<table>
<thead>
<tr>
<th>Mode Name</th>
<th>Control Variable</th>
<th>Breath Sequence</th>
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<tbody>
<tr>
<td>Pressure Control A/C</td>
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<td>CMV</td>
<td>set-point</td>
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<td>CSV</td>
<td>servo</td>
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<td>adaptive</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Part 1: Summary

• A mode is a particular pattern of patient-ventilator interaction

• A mode **name** is arbitrary (marketing device)

• A mode **tag** follows a logical taxonomy
  – control variable
    ◦ *breath sequence*
    ◗ *targeting scheme*

• Modes can be described at any level of detail that is appropriate for the need
  – volume control vs pressure control
  – CMV vs IMV vs CSV
  – VC-CVM
    ◆ setpoint vs PC-IMV
    ◆ adaptive
Part 2: How Do We Select Modes
1. Memorize Key Terminology (Standardized Vocabulary)

2. Know Ten Maxims of Ventilator Technology

3. Classify All Available Modes

4. Compare Modes

5. Use Modes
AIM Before You ACT

Patient

Assess Patient Needs
Identify Treatment Options

Identify Ventilation Goals

Match Technology to Patient Needs

Identify Available Modes
Assess Patient Needs

- Safety
- Comfort
- Liberation

Identify Available Modes
Patients

Safety Comfort Liberation

1. Modes
2. Settings

Match Technology to Patient Needs
Relate Goals to Ventilator Features

GOALS OF MECHANICAL VENTILATION

Objectives Serving Goals
Aims of Clinical Management
Capabilities of Ventilators
Features of Specific Modes

A Rational Framework for Selecting Modes of Ventilation.
Mireles-Cabodevila E, Hatipoglu U, Chatburn RL.
Respir Care 2013;58(2):348–366
SAFETY

Optimize ventilation/perfusion of the lungs

Maximize alveolar ventilation

Automatic adjustment of support in response to changing lung mechanics

Ventilator set inspiratory pressure

Example mode: VC+ (Covidien PB 840)

Respir Care 2013;58(2):348–366
Optimize patient-ventilator synchrony

Maximize trigger/cycle synchrony

Trigger/cycle based on diaphragm electromyography

Operator set trigger threshold based on amplitude of Edi

Example mode: NAVA (Maquet Servo i)
LIBERATION

Optimize weaning experience

Minimize duration of ventilation

Ventilator initiated weaning of support

Ventilator adjusts pressure support and attempts spontaneous breathing trial

Example mode: SmartCarePS (Dräger Evita XL)
Safety – Technological Capabilities

- Automatic adjustment of minute ventilation target
- Automatic adjustment of support in response to changing respiratory system mechanics
- Automatic adjustment of oxygen delivery
- Automatic adjustment of end expiratory lung volume
- Automatic adjustment of lung protective limits
- Automatic adjustment of tidal volume
- Minimization of tidal volume (HFV)
- Manual adjustment of minute ventilation parameters
Comfort – Technological Capabilities

• All breaths can be spontaneous
• Trigger/cycle based on chest/diaphragm movement
• Coordination of mandatory vs spontaneous breaths
• Automatic limitation of autoPEEP
• Unrestricted inspiratory flow
• Automatic adjustment of flow based on frequency
• Automatic adjustment of support to maintain specific breathing pattern
• Automatic adjustment of support to meet demand
Liberation – Technological Capabilities

• Ventilator initiated weaning of support
• Ventilator recommends liberation
• Automatic reduction of support in response to increased patient effort
The Toolbox
Ventilators Used for Neonates

Covidien PB 840

Maquet Servo-i

Draeger VN 500 Babylog

CareFusion Avea

Hamilton G5
SLE 5000 Neonatal Ventilator with HFO

GRAPHNET neo

STEPHANIE with HFO
The Tools
No volume control modes!
The Evidence
MEASUREMENTS AND RESULTS:
ICU ventilators responded faster or greater than the Babylog with respect to: pressure to trigger (except the Servo i), time to trigger (except the Evita XL), time between trigger and return of pressure to baseline, time from start of breath to 90% of peak pressure (except the Avea) and pressure time product of breath activation. Expiratory tidal volume was also greater with all ICU ventilators except the Avea.

CONCLUSION:
All ICU ventilators tested were able to at least equal the performance of the Babylog 8000 Plus on all variables evaluated.
RCTs generally for RDS and severe RF

Meta-analyses show no benefit of patient triggered ventilation or HFO

Need more, better studies

Need better understanding of how ventilator work
  – Many modes
  – Many variations of ventilator design
• SIMV vs IMV associated with shorter duration ventilation
• Only short term benefits of newer modes
  — PSV, VTV, NAVA
• Favorable results of HFO not confirmed
• Randomized studies with long term outcomes needed
Meta-analyses using the Cochrane statistical package

Eighteen trials met inclusion criteria

No evidence that VTV modes reduced mortality

VTV modes did reduce

- bronchopulmonary dysplasia (RR 0.61)
- duration of ventilation and oxygen (2 days, 1.7 days)
- intraventricular hemorrhage (RR 0.65)
- pneumothorax (RR 0.56)
Problems with neonatal volume control

• Ventilator controls volume to circuit, not to patient
  – compressible gas loss
  – variable leaks due to un-cuffed tubes
  – no standardization of exhaled vs inhaled $V_T$
Tracheal tube airleak in clinical practice and impact on tidal volume measurement in ventilated neonates.

Mahmoud RA, Proquitté H, Fawzy N, Bührer C, Schmalisch G.

MEASUREMENTS AND RESULTS:
A TT leak of >5% was seen in 75% infants. Neonates with TT leak, compared with those without TT leak, had a longer duration of mechanical ventilation, a lower gestational age, and a higher prevalence of reintubation. The greatest TT leak was seen in infants ventilated with a TT of <3-mm diameter.

CONCLUSION:
TT leak is highly variable, and TT leak of >40% with clinically relevant $V_T$ errors occurred in nearly half of all ventilated neonates. Preterm infants of low birth weight and with small-diameter TTs ventilated for a long period were at greater risk of TT leak.
The Effect of Airway Leak on Tidal Volume during Pressure- or Flow-Controlled Ventilation of the Neonate: A Model Study

Robert L Chatburn RRT, Teresa A Volsko RRT, and Mohamad El-Khatib PhD

RESPIRATORY CARE • AUGUST ’96 VOL 41 NO 8

\[ \% \Delta V_E = \frac{V_E \text{ (leak off)} - V_E \text{ (leak on)}}{V_E \text{ (leak off)}} \times 100 \]

PC resulted in significantly smaller leak effect than VC for all conditions except small \( V_T \) and short \( T_i \)

During VC, a leak acts like a pressure limiting mechanism thus VC becomes PC with an unknown PIP
Modes on Dräger VN 500
(aka, volume targeted or volume guarantee)

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<tbody>
<tr>
<td>Pressure Control A/C (with Volume Guarantee)</td>
<td>pressure</td>
<td>CMV</td>
<td>adaptive</td>
<td>N/A</td>
</tr>
<tr>
<td>Pressure Control CMV (with Volume Guarantee)</td>
<td>pressure</td>
<td>IMV</td>
<td>adaptive</td>
<td>set-point</td>
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<tr>
<td>Pressure Control Mandatory Minute Volume Ventilation (with Volume Guarantee)</td>
<td>pressure</td>
<td>IMV</td>
<td>adaptive</td>
<td>set-point</td>
</tr>
<tr>
<td>Pressure Control SIMV (with Volume Guarantee)</td>
<td>pressure</td>
<td>IMV</td>
<td>adaptive</td>
<td>set-point</td>
</tr>
<tr>
<td>Pressure Control Pressure Support Ventilation (with Volume Guarantee)</td>
<td>pressure</td>
<td>IMV</td>
<td>adaptive</td>
<td>set-point</td>
</tr>
</tbody>
</table>
Work of Breathing in Adaptive Pressure Control Continuous Mandatory Ventilation

Eduardo Mireles-Cabodevila MD and Robert L Chatburn RRT-NPS FAARC

Respir Care 2009;54(11):1467–1472
Volume-targeted ventilation in infants born at or near term.

Chowdhury O, Rafferty GF, Lee S, Hannam S, Milner AD, Greenough A.

RESULTS:
One infant became apnoeic at $V_T$ of 6 ml/kg. At a $V_T$ level of 4 ml/kg, four infants were making such vigorous respiratory efforts that no inflations were delivered.

CONCLUSION:
Low $V_T$ levels (4 ml/kg) during VTV increase the WOB in ventilated infants born at term or near term. The results suggest that a $V_T$ level of 6 ml/kg could be used to reduce the WOB.
**RESULTS:**

$V_T$ levels were more stable, and the PIP levels were significantly decreasing in the VG group. Although the duration of ventilation was shorter in the VG group but not statistically significant. The incidences of death BPD were not different, but the combined outcome of death or BPD was lower in the VG group. VG group had less BPD, periventricular leukomalacia, and intraventricular hemorrhage, but not statistically different.

**CONCLUSION:**

VG with A/C (in the acute phase of RDS) and SIMV (in the weaning), reduced $V_T$ variability and may have shortened the duration of ventilation in VLBW infants. Overall mortality and BPD rates did not change, but their combined outcome was significantly improved in infants treated with VG modes as compared to those treated with PC-SIMV.
RESULTS:
During suction, PIP increased and $V_T$ was maintained, except with large catheter relative to the ETT when $V_T$ decreased. End-expiratory pressure distal to the ETT was reduced during suction by up to 75 cm H$_2$O while PEEP was unchanged. Following suction, pressures and tidal volume increased to baseline in 8-12 s.

CONCLUSION:
Closed ET suction interferes with ventilator function for VG, with the potential for high airway pressures and tidal volumes following the procedure.
An international survey of volume-targeted neonatal ventilation.

Klingenberg C, Wheeler KI, Owen LS, Kaaresen PI, Davis PG.

RESULTS:
VTV was routinely used in 50% of units. The most common reason given for using VTV was that it reduces bronchopulmonary dysplasia. The median of target tidal volume were

- 4.6-6.0 ml/kg for initial ventilation of infants with RDS
- 5.0-8.0 ml/kg infants with ventilator-dependent BPD

CONCLUSION:
Half of the units used VTV routinely, but with a considerable variation in VTV practice. More studies are required to establish best VTV practice.
Modes on Dräger VN 500 (adaptive targeting)

<table>
<thead>
<tr>
<th>Mode Name</th>
<th>Control Variable</th>
<th>Breath Sequence</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Pressure Control Mandatory Minute Volume</td>
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<td>IMV</td>
<td>adaptive</td>
<td>set-point</td>
</tr>
<tr>
<td>Ventilation (with Volume Guarantee)</td>
<td>pressure</td>
<td>IMV</td>
<td>adaptive</td>
<td>set-point</td>
</tr>
</tbody>
</table>

IMV but spontaneous breaths suppress mandatory breaths
RESULTS:
No differences were found for etCO$_2$, minute volumes, PIP, or PEEP. However, there was a significant difference in the type of ventilator breaths given and in the mean airway pressure. Additionally, there was a statistically significant negative trend in MMV over time compared to SIMV, although this was subtle and could have been due to extreme cases.

CONCLUSIONS:
Neonates with an intact respiratory drive can be successfully managed with MMV. While this mode generates similar PIP and PEEP, the decrease in mandatory breaths and the mean airway pressure generated with MMV may reduce the risk of some of the long-term complications associated with mechanical ventilation.
Modes on Dräger VN 500
(Continuous Spontaneous Ventilation)

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<tr>
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</tr>
<tr>
<td>Spontaneous Proportional Pressure Support</td>
<td>pressure</td>
<td>CSV</td>
<td>servo</td>
<td>N/A</td>
</tr>
<tr>
<td>Spontaneous CPAP/Volume Support</td>
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</tr>
</tbody>
</table>
Proportional Pressure Support (Dräger)
(aka Proportional Assist Ventilation)

\[ P_{\text{vent}} + P_{\text{mus}} = EV + RV' \]

Flow Assist: pressure proportional to flow

User sets elastic and resistive unloading

Volume Assist: pressure proportional to volume
Randomized Crossover Comparison of Proportional Assist Ventilation and Patient-triggered Ventilation in Extremely Low Birth Weight Infants with Evolving Lung Disease

Schulze et al Neonatology 2007;92(1):1-7

RESULTS:
Lower mean mean and peak airway pressure with PAV
No difference in oxygenation

CONCLUSION:
PAV safely maintains gas exchange at lower pressures than PTV without adverse effects
Result:
When compared to PC-CMV, neonates ventilated with NAVA had lower PIP, FiO$_2$, transcutaneous, Edi peak and RR. There was an increase in expiratory tidal volume, compliance and Edi minimum. Despite lower PIP and RR, partial pressure of PCO$_2$ was lower when ventilated on NAVA. There was no difference in mean airway pressure.

Conclusion:
Premature neonates ventilated with NAVA required less PIP, FiO$_2$ and RR to achieve lower PCO$_2$ and better compliance compared with PC-CMV.
366 eligible preterm infants were randomly assigned to treatment with HFOV or PC-SIMV.

PC-SIMV with PS
  - Death or BPD was higher

HFOV
  - Duration of mechanical ventilation less
  - Hospitalization was shorter
  - Incidence of surfactant requirement lower
  - Retinopathy of prematurity lower
• Meta-analyses using the Cochrane statistical package
• Determine the effect NIPPV compared with NCPAP on the need for additional ventilatory support
• NIPPV reduces extubation failure more effectively than NCPAP
• No effect on chronic lung disease or mortality
• Synchronisation and device design may be important
Time cycled pressure-limited ventilation is the most commonly used mode in neonatal ventilation

Tidal volumes are usually targeted between 4 to 7 mL/kg

PEEP level is usually 4-6 cm H₂O

Newer ventilation modes are only used in a minority of patients
Part 2: Summary

• No conclusive data that any one mode is better than another
  — And there probably never will be
• Assess the goal of mechanical ventilation
• Identify mode features that serve goal
“A computer lets you make more mistakes faster than any invention in human history-with the possible exceptions of handguns and tequila”

Rich Radcliffe