AUTOMATED VENTILATION FOR PATIENT SAFETY

Ron Sanderson
DrPH, MEd, RRT, RPFT, AE-C
WHAT ARE WE TALKING ABOUT?

Presentation Outline

• Establish the need for increased Patient Safety
• Describe the risks of mechanical ventilation
• Introduce Automated Ventilation
• Drill down specifics of Automated Ventilation
• Explore quality measures for use of Automated Ventilation for Patient Safety
• Errors are not tolerated in Commercial Aviation, nor should they be in Medicine.
200,000 Lives Lost Due To Medical Error!

- IOM 1999 “To err is human” reported 98,000 lives lost due to medical error.
- 2007 Journal of Patient Safety reports 210,000 - 440,000
- 2010 OIG DHHS reports 180,000 lives lost in medicare alone
- 2018 John’s Hopkins reports >250,000 lives lost
Two 747s going down in the U.S.A. everyday!
= 182,000/year
Evaluation of User-Interface Simplicity and Human Errors in Modern Generation Mechanical Ventilators

When given ventilator setup, vent changes and alarm response tasks:

experienced operators made 11% errors

Newly trained operators made 23% errors

Uzawa Y et al. Respir Care 2008;53(3):329-337
We have been working very hard to save lives.

<table>
<thead>
<tr>
<th>ARDS Mortality reported by:</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Diamond</td>
<td>2020</td>
<td>27 – 45%</td>
</tr>
<tr>
<td>Charalampos</td>
<td>2012</td>
<td>41 - 46%</td>
</tr>
<tr>
<td>ARDS Network</td>
<td>2009</td>
<td>26 – 35%</td>
</tr>
<tr>
<td>ARDS Net</td>
<td>2000</td>
<td>31 - 46%</td>
</tr>
<tr>
<td>Brochard</td>
<td>1998</td>
<td>38 – 47%</td>
</tr>
<tr>
<td>Montgomery</td>
<td>1985</td>
<td>68%</td>
</tr>
<tr>
<td>Downs/Kirby</td>
<td>1975</td>
<td>19 – 39%</td>
</tr>
</tbody>
</table>

But we haven’t made much progress in 45 years.
Risks of Mechanical Ventilation

Barotrauma
Atelectrauma
Volutrauma
Pneumothorax
Absorption atelectasis
Oxygen toxicity
Alveolar distention
Aspiration
Near-drowning
ICU delirium, PTSD
Hypercapnia
Hypocapnia
Hypoxia
Suffocation
Death

Pressure necrosis (oral, facial or tracheal)
Vocal cord paralysis
Trauma (due to intubation or suction)
Infection
Decreased blood pressure
Reduced cerebral blood flow
Fluid overload
Decreased cardiac output
Decreased coronary vessel perfusion
Decreased cerebral perfusion pressure
Decreased renal perfusion
Decreased urine output
Tracheomalacia
Over sedation
Most Powerful Ventilator Safety Intervention:

Get the Patient off the ventilator!

Reduce Ventilator Length of Stay

Reduce Risk of injury or death:
Highest Risk at ventilator initiation
High Risk intra-hospital transport
Beyond that it is high risk all the time
Forces driving ICU ventilator care

• Patient survival
• Patient safety (alarms, OVP, monitoring, etc.)
• Ventilator/Patient Protocols
• Financial pressure
• Professional staff stressors
• Patient/Family Psychosocial influences
• Ventilator Associated Event (VAE) prevention
• Extremely complex modality
• Same old processes, habits….inertia?........................
It is the process, not the people.

Systems Approach to Error Reduction
Are you sure about that?
How Can Automated Ventilation Increase Patient Safety?

What is “Automation”?
Types of Closed Loop Automation

1. Set point and adaptive dual control modes – good first step (Car cruise control Automated heated wire circuit)

2. Automated initialization of CMV

3. Optimal dual control mode with multivariate feedback – long term solution
Simple Closed Loop Ventilator Systems

Simple control options available on the market:
VAPS, PRVC, APV  ETC........................

Monitor: One or two parameters
(Tidal Volume, minute volume)

Change: One or two parameters
( Inspiratory pressure, frequency)
Automation in Initiation of CMV

Why?

Mass Casualty

Flu Pandemic increased ICU capacity

iVent
LTV-1200
Uni-vent Eagle
Multi-variable Closed Loop
“Embedded Ventilator Protocols”

• Hamilton Galileo, G-5, T1, C1, C2, C3, MR1 & S-1
  Adaptive Support Ventilation  (Apnea to extubation)

• Drager Evita – “Smart Care”
  (Spontaneous ventilation to extubation)

• Covidien/PB 840, 980  Proportional Assist+
  (Spontaneous ventilation to extubation)

• Maquet Servo I, Neurally Adjusted Ventilatory Assist
  (NAVA)  (Spontaneous ventilation to extubation)
Adaptive Support Ventilation

- Intelligent Ventilation
- Available in Europe 1990s
- Available in USA 1998
Automation is an assistant who:

• Monitors the patient every breath
• Watches the important parameters
• Responds appropriately to every change
• Never becomes tired or bored
• Saves MD/RT/Nurse much time and trouble
Imagine

• Your best practitioner at the bedside making appropriate changes every time.
• Never distracted
• Never takes a break
• Always follows correct protocol
Closed Loop Control Goals?

- Automating Evidence Based Medicine for lung protection, weaning......
- Minimizes variation in ventilator management
- Adapt to patient status, decreasing modes and setting changes
- Optimizes the use of the limited system resources.
Intelligent Ventilation

- Suitable for all phases of ventilation, including weaning
- A NON-MODE that adapts ‘mode’ to patient needs
- Automatic selection of tidal volumes – even in ARDS
- Automatic weaning, only when appropriate
- Automatic adaptation to all patients
Automated Lung Protective Ventilation SAVES LIVES

Adoption of Automation at Castle Medical Center 2003-2008

(1271 total vent patients)
n = all patients (non-random)

Three Categories of Patients:

577  ASV only (start to finish)
135  Switched to ASV
526  Conventional ventilation

Patient’s average age = 66 y.o ; 54% female
### ASV experience at Castle Medical Center

(A Case Report Series)

<table>
<thead>
<tr>
<th>#Pt</th>
<th>Method</th>
<th>Year</th>
<th>% of total</th>
<th>Vent. LOS (Days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>36</td>
<td>ASV only</td>
<td>2003</td>
<td>23%</td>
<td>2.5</td>
</tr>
<tr>
<td>93</td>
<td>No ASV</td>
<td>2003</td>
<td>50%</td>
<td>4.2</td>
</tr>
<tr>
<td>170</td>
<td>ASV only</td>
<td>2008</td>
<td>84%</td>
<td>3.6</td>
</tr>
<tr>
<td>23</td>
<td>No ASV</td>
<td>2008</td>
<td>11%</td>
<td>7.9</td>
</tr>
</tbody>
</table>

(2003 n = 159, 2008 n = 203)
We use ASV on any:

- Post-operative patient
- Emergency room patient
- Acute Respiratory Failure
- ARDS
- Asthma
- COPD
- Neurological patient
- Drug overdose
ASV experience at Castle Medical Center

ASV may be used safely.

ASV can move patient from full support to extubation without any changes.

ASV preferred by respiratory therapists, ICU nurses and most physicians.

ASV more patient comfort and less alarms.
Hamilton Medical Ventilators

G-5
Automated Ventilation
Closed-Loop
Intelligent Ventilation
Adaptive Support
Ventilation

T-1

C-6
Galileo

Hamilton Medical Ventilators
Respiratory Failure

Two Problems:

- Ventilation (ASV is a solution)
- Oxygenation (PEEP & $F_{1}O_{2}$)
Ventilatory Failure

Only Four Problems.....?

- Airway Resistance
- Lung/Thorax Compliance
- Respiratory Drive
- Work of Breathing

ASV is a solution
Adaptive Support Ventilation

No manual mode change. ASV adapts automatically to the needs and capabilities of the patient.
How does PATIENT ORIENTED Intelligent Ventilation work?

For any combination of resistance, compliance, V’ a and Vd, there is a respiratory rate where WOB is minimal.

Automated Ventilator System

Hamilton G-5: ASV

Monitors & Reports to Microprocessor

- Minute volume
- Tidal volume
- Expiratory Resistance
- Lung/Thorax Compliance
- Frequency, control
- Frequency, spontaneous
- Peak inspiratory pressure

Computer - Changes

- Mode of ventilation
- Inspiratory pressure
- Inspiratory time
- Respiratory frequency

Expiratory

Time Constant
5 Test Breaths.....

(example)

1. SIMV = 15/minute  
2. PCV = 15 cmH₂O  
3. Insp. Time = 1 second
The microprocessor
Assesses patient: 5 test breaths

Pressure \times \text{time} \quad \text{causes} \quad \text{Flow}

1: R_C e, V_t, f
2: ...
3: ....
4: ....
5: R_C e, V_t, f
Calculate optimal breath pattern:

Calculate $V_T$

Frequency in breaths per minute

$V_T$ in ml

$f_{\text{target}}$

$V_T^{\text{target}}$
Calculate -
optimal breath pattern:
Lung protective strategy

Avoid:
a: apnea
b: volu/barotrauma
c: AutoPEEP
d: excessive $V'_D$/tachypnea

Frequency in breaths per minute

Vt in ml
Adjust Pinsp and mand. Rate to meet targets: Principle
Adjust Pinsp and mandatory rate to meet targets: Dynamics

![Diagram showing adjusting of Pinsp and PEEP with less than 60 sec]
Maintain optimal breath pattern

Re-assess patient breath-by-breath
\((R\overline{C}_e, V_T, f)\)

Re-calculate optimal breath pattern
\((V_{\text{Target}}, f_{\text{Target}})\)

Adjust \(P_{\text{insp}}\) & mand.rate to meet target
\((P_{\text{insp}}, f_{\text{mand}}, I:E \text{ ratio})\)
Control breaths are “PCV-SIMV”

Spontaneous breaths are “PSV”
Basically control mode; PCV-SIMV, Medical coma, vent doing all breaths

- Target and Current points
- MinVol 10.8 L/min
- Volume (V) in ml
- Frequency (f) in b/min
- Spontaneous (fSpont) 0 b/min, Controlled (fControl) 20 b/min, Ppin 21 cm H2O
Patient getting well; initiating breaths, PCV-SIMV
Basically spontaneous mode, PCV-SIMV, ready to discontinue vent.
“Vent monitor with ventilation goals”
ASV uses low $V_T$ strategy

$V_T$ typically 5 - 7 ml/Kg for ARDS patients

Lower $V_T$ similar to report from NEJM, 342:18, 1301-08, May 4, 2000
Adaptive Support Ventilation (ASV®) automatically adapts a protective ventilation in ARDS patients.

Arnal JM, Wysocki M, Garcin F, Donati SY, Granier I, Durand-Gasselin J.
Intelligent Ventilation/ASV

Improved Patient Outcomes

• **ASV reduces weaning time.**


• **ASV automatically selects a breathing pattern that fits the patient’s pathology.**

Intelligent Ventilation - Operator/ventilator reactivity

- Less changes required
- Reacts to patient more frequently
- Fewer alarms

Sulzer, Anesthesiology, 2001
Petter, Anesth Analgesia, 2003
ASV meets clinician set goals in one to three minutes.
Patient feels relief almost immediately.
We still need physicians, nurses and respiratory therapists.

ASV cannot make clinical decisions.
“Yesterday there was a homeless person here. I told you automation can replace anybody.”
Drager Evita XL
The 3 Monitored parameters: 

- $f_{spont}$
- $V_T$
- $etCO_2$

8 Classifications

1. Normal Ventilation
2. Insufficient Ventilation
3. Hypoventilation
4. Central Hypoventilation
5. Tachypnea
6. Severe Tachypnea
7. Unexplained Hyperventilation
8. Hyperventilation

The Hypoventilation

- Tachypnea
- Severe Tachypnea
- Unexplained Hyperventilation
- Hyperventilation
<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>fspn</th>
<th>VT</th>
<th>etCO₂</th>
<th>SC response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal ventilation</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>↓ PS by 2 or 4</td>
</tr>
<tr>
<td>Insufficient ventilation</td>
<td>OK</td>
<td></td>
<td>OK</td>
<td>↑ PS by 2 or 4</td>
</tr>
<tr>
<td>Hypoventilation</td>
<td></td>
<td>OK</td>
<td>OK</td>
<td>↑ PS by 4</td>
</tr>
<tr>
<td>Central Hypoventilation</td>
<td></td>
<td></td>
<td></td>
<td>ALARM</td>
</tr>
<tr>
<td>Tachypnea</td>
<td></td>
<td></td>
<td></td>
<td>↑ PS by 2 or 4</td>
</tr>
<tr>
<td>Severe Tachypnea</td>
<td></td>
<td></td>
<td></td>
<td>ALARM</td>
</tr>
<tr>
<td>Hyperventilation</td>
<td></td>
<td>OK</td>
<td>OK</td>
<td>↓ PS by 4</td>
</tr>
<tr>
<td>Unexplained Hyperventilation</td>
<td></td>
<td></td>
<td></td>
<td>ALARM</td>
</tr>
</tbody>
</table>

Overview of patient classifications and SmartCare response.
**SmartCare/PS™ the clinical evidence**

<table>
<thead>
<tr>
<th>OUTCOME</th>
<th>CDW group (N = 74)</th>
<th>Usual weaning group (N = 70)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to first extubation †</td>
<td>2.00 (1.75-6.25)</td>
<td>4.00 (2.00-8.25)</td>
<td>0.02</td>
</tr>
<tr>
<td>Duration of mechanical ventilation until first extubation †</td>
<td>6.50 (3.00-12.25)</td>
<td>9.00 (5.75-16.00)</td>
<td>0.03</td>
</tr>
<tr>
<td>Time to successful extubation *</td>
<td>3.00 (2.00-8.00)</td>
<td>5.00 (2.00-12.00)</td>
<td>0.01</td>
</tr>
<tr>
<td>Total duration of mechanical ventilation *</td>
<td>7.50 (4.00-16.00)</td>
<td>12.00 (7.00-26.00)</td>
<td>0.003</td>
</tr>
<tr>
<td>Intensive care length of stay</td>
<td>12.00 (6.00-22.00)</td>
<td>15.50 (9.00-33.00)</td>
<td>0.02</td>
</tr>
<tr>
<td>Hospital length of stay</td>
<td>30.00 (17.00-54.75)</td>
<td>35.00 (21.00-60.25)</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Drager Evita – Smart Care

Comments:
- Patient must be breathing spontaneously
- Protocol automatically performs spontaneous breathing trial
- Alarms when outside limits
- Has apnea backup and ATC
- Patients may change more rapidly than every 15 – 60 minutes
Neurally Adjusted Ventilatory Assist

Maquet – Servo-I

NAVA
NAVA senses activity in the diaphragm and responds by providing the requested level of ventilatory assist. The Edi signal is obtained by an electrode array mounted close to the distal tip of the Edi catheter. This catheter can also serve as a conventional nasogastric feeding tube.
Maquet – Servo-I NAVA

**Improved synchrony**: the ventilator is cycled-on as soon as neural inspiration starts.

Maquet – Servo-I NAVA

**Lung protection:** With NAVA avoid over or under assistance of the patient.

**Unique monitoring capability:** In all ventilation modes, providing information on Respiratory Drive, Volume requirements and the effect of the ventilator settings, and to gain indications for sedation and weaning.
Maquet – Servo-I NAVA

**Patient comfort:** The delivered assistance is matched to neural demands to minimize patient discomfort and promoting spontaneous breathing.

**Decision support for unloading and extubation:** As the patient’s condition improves, Edi amplitude decreases, resulting in reduction in ventilator-delivered pressure. This pressure drop is an indicator to consider weaning and extubation.

Maquet – Servo-I

Comments:
- Patient must be breathing spontaneously
- Protocol automatically performs spontaneous breathing trial
- Alarms when outside limits
- NG tube is a little difficult
PAV+

• The WOB bar displays total (WOBtot) and the patient (WOBpt).

Work of breathing calculated using the equation of motion.

• When R and E are known, it’s possible to calculate (Pmusc) & WOB
  \[ P_{MUSC} + P_{VENT} = (\text{flow} \times \text{resistance}) + (\text{volume} \times \text{elastance}) \]

• PAV+ measures resistance and compliance every 4-10 breaths.
• Once %Support is set, clinicians use (WOB) bar for feedback on
  pt WOB vs. vent WOB
Fatigue values for work of breathing are shown as being outside the green zone.

WOB bar and clinical assessment, determine level of ventilator support.

WOB feedback keeps the patient at a sustainable level of work—reducing respiratory muscle atrophy, but off-loading enough work to avoid fatigue.
Covidien – PB840 & PB980

Comments:

- Patient must be breathing spontaneously
- Focuses on WOB
- Alarms when outside limits
Other Automation

- Open Lung Maneuvers (Recruitment)
- Ramping up pressure or volumes
- ET tube compensation
- Oxygenation - changing PEEP & $\text{F}_1\text{O}_2$
- Monitoring weaning goals and reporting
Automated Recruitment Maneuver and Inflection Points
How do We Know if We are doing Better?

What is the Quality Measure for Ventilator Patient Safety?

Ventilator Length of Stay (VLOS)
What Contributes to Ventilator LOS?

Conventional Wisdom: The ventilator LOS is a function of the patient’s disease process.

(just reverse the pathology and wean the patient)

- Expiratory Resistance
- Lung/thoracic compliance
- Respiratory drive
- Respiratory muscle strength
- Improve oxygenation
What Contributes to Ventilator LOS?

• Critical thinking – ventilator LOS is a function of many factors in addition to the patient’s underlying pathology

  – Correct diagnosis and treatment
  – Decision to intubate and ventilate
  – Patient/family attitudes and wishes
  – Physician’s ventilator management style
  – ICU teamwork
Why is Ventilator LOS Important?

- Patient safety
- Quality of care
- Cost to the hospital
- Cost to payors
What is the Ventilator LOS in Your Medical Center?

- Do you know it?
- How is it measured?
Assess Patient safety
Using Ventilator LOS

• Each unnecessary day on a ventilator in ICU exposes the patient to increased chance of healthcare related infections, injury, and death.

• Your worst nightmare? My worst nightmare........ being on a ventilator!
Assess Quality of Care Using Ventilator LOS

Ability to implement ventilator care improvement tactics and measure outcomes

- New equipment
- New techniques
- New processes and/or protocol
- Changes in staffing
Assess Cost to the Hospital Using Ventilator LOS

• Reduced ventilator LOS has been clearly correlated with reduced ICU LOS and hospital LOS
• This “thru put” increases opportunity for reimbursement
Ventilator Discontinuation

Controversies:

T-piece trial vs

SIMV vs

Pressure support

Spontaneous Breathing Trial (SBT) either

T-piece or low level pressure support (PS)

Eur Respir J 2007; 29: 1033–1056
Ventilator Management
Standard of Care

• There is no clear standard of care
• Physician specific management styles
• Hospital standards vary
• Community standards vary
• State – no standards
• National – few standards
• International – few standards
Use of Ventilator Protocols

- Patient driven
- Therapist driven
- Nursing protocols
- Microprocessor embedded

If you don’t measure it; you can’t assess interventions
Improve our end-of-life conversations

- Palliative care
- Futile care
- Comfort measures
- Code Status
Summary

Take home message:

1. Appreciate Importance of Patient Safety
2. Embrace Increased use of Automation
3. Learn how to measure ventilator length of stay accurately

“If you can’t measure it; it doesn’t count”
THE END