New Modes to Enhance Synchrony &

Dietrich Henzler MD, PhD, FRCPC
Division of Critical Care

Department of Anesthesia
Disclosure
Conflicts of Interest 2001–2011

Research Grants & Payments (cost reimbursements, speaker fees)

- Draeger Medical
- Air Liquide
- Hamilton Medical
- Hospira
- Fresenius Kabi
“The patient should not be unduly burdened, nor should the medical team rely on a ventilator set at the progressively lower rate to forestall disaster if the patient is not ready.
“The patient should not be unduly burdened, nor should the medical team rely on a ventilator set at the progressively lower rate to forestall disaster if the patient is not ready. Discontinuation from ventilation requires no
Closed loop ventilation

- Intermittent Mandatory Ventilation 1975
- Pressure Support Ventilation 1981
- Proportional Assist Ventilation 1992
- Automatic tube compensation 1994
- Neurally Adjusted Ventilator Assist 1999
- Adaptive Support Ventilation 1994
- Smart Care 2004
Physiologic Breathing control

Central controller

Input

Sensors
- Chemoreceptors
- Lung, peripheral

Output

Effectors
- Respiratory muscles

Pons, medulla
Mechanical Breathing Cycle

Inspiration

- Tidal volume
- Brain
- Phrenic nerve activation
- Diaphragm contraction
- Lung expansion
- Airflow ↑

Expiration
Mechanical Breathing Cycle

Inspiration

Brain

Phrenic nerve

Diaphragm activation

Diaphragm contraction

Lung expansion

Airflow ↑

Hering-Breuer

Expiration

Phrenic nerve

Deflation

Diaphragm de-activation

Diaphragm relaxation

Airflow ↓
Mechanical Breathing Cycle

- **Inspiration**
  - Tidal volume
  - Airflow ↑
  - Lung expansion
  - Phrenic nerve
  - Diaphragm activation

- **Expiration**
  - Phrenic nerve de-activation
  - Diaphragm relaxation
  - Deflation
  - Airflow ↓

- **Brain**

- **Hering-Breuer**
Mechanical Breathing Cycle

Inspiration

- Brain
- Tidal volume
- Airflow ↑
- Lung expansion
- Diaphragm contraction
- Diaphragm activation
- Hering-Breuer

Expiration

- Phrenic nerve
- Deflation
- Airflow ↓
- Diaphragm relaxation
- Diaphragm de-activation
Inspiratory Dyssynchrony

- Trigger delay

- Ineffective trigger
  - wasted effort
  - Auto-trigger
  - Double trigger

- Inappropriate response
  - Overshoot
  - undersupport
1. Start of patient effort
2. Generation of negative pressure / flow
3. Ventilator sensing (DT, triggering delay)
4. Ventilator action (DI, inspiratory delay)
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Inspiratory Dyssynchrony

• **Trigger delay**

• **Ineffective trigger**
  • wasted effort
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• **Inappropriate response**
  • Overshoot
  • undersupport

Colombo D. Crit Care Med 2011; 39:2452-2457
Expiratory Dyssynchrony
Expiratory Dyssynchrony

- Premature termination
  - Insufficient support
  - Tachypnoea, rapid shallow breathing
Expiratory Dyssynchrony

• Premature termination
  • Insufficient support
  • Tachypnoea, rapid shallow breathing

• Delayed termination
  • Airflow obstruction
  • Patient “fighting” the ventilator
1. Start of electrical diaphragmatic activity / patient effort
2. End of patient breath
3. End of ventilator breath – expiratory sensitivity - timed ending
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Clinical consequences

• Instability
  • Pulmonary
    • Added work of breathing
    • Patient “fighting” the ventilator, desaturation
  • Hemodynamically

• Need for sedation

• Delirium

• ICU length of stay, mortality
Clinical consequences

- 24% of patients (n=62, mech.vent.>24h) exhibited asynchrony index >10%
- Modes investigated PSV, A/C

<table>
<thead>
<tr>
<th>Duration of mechanical ventilation (days; IQR)</th>
<th>Asynchrony index &lt; 10% (n=47)</th>
<th>Asynchrony index ≥ 10% (n=15)</th>
<th>p</th>
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<tbody>
<tr>
<td>Duration of mechanical ventilation ≥ 7 days</td>
<td>7 (3–20)</td>
<td>25 (9–42)</td>
<td>0.005</td>
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<tr>
<td>Tracheostomy</td>
<td>23 (49%)</td>
<td>13 (87%)</td>
<td>0.01</td>
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<td>Mortality</td>
<td>2 (4%)</td>
<td>5 (33%)</td>
<td>0.007</td>
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<td></td>
<td>15 (32%)</td>
<td>7 (47%)</td>
<td>0.36</td>
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Characteristics of “new modes”

• Triggering
  • Minimize delay

• Appropriate support
  • Adjust ventilation to need
  • Adjust support to minimize WoB
  • Adjust support to demand
Breathing Cycle

Inspiration

Airflow ↑

Tidal volume

Lung expansion

Diaphragm contraction

Diaphragm activation

Hering-Breuer

Expiration

Airflow ↓

Phrenic nerve

Diaphragm de-activation

Diaphragm relaxation

Fixed Settings

Frequent adjustments required
Automated Tube Compensation

\[ P_{res} = \dot{V} \times R \]
Automated Tube Compensation

\[ P_{res} = \sqrt{\cdot R} \]

PS

Flow

Automated Tube Compensation

\[ P_{\text{res}} = \sqrt{v \times R} \]
Automated Tube Compensation

\[ P_{res} = \sqrt{\cdot} \times R \]

Flow

Under-compensation

overcompensation

PS

Automated Tube Compensation

\[ P_{\text{res}} = \sqrt{\cdot \times R} \]

Appropriate setting

Under-compensation

overcompensation

Flow

ATC – Application

Calculation of added WoB (tube resistance) depending on inner diameter and length (Rohrer’s Eq.)

\[ \Delta P_{ETT} = K_1 \times \dot{V} + K_2 \times \dot{V}^2 \]
ATC – clinical studies

• Cross-over study in 12 surgical pts. Ready to wean

• ATC vs. PS 7 cmH$_2$O vs. T-Piece

• Measurement of WoB and PTP

Kuhlen R et al. European J Anaesthesiology 2003; 20: 10–16
ATC – Conclusions

ADVANTAGES

- Unloads from added work of breathing
- Facilitates “electronic extubation”

LIMITATIONS

- Uses fixed assumptions according to tube size
- No consideration of changes in tube resistance
- No no adjustments for change in patient airway resistance
- Clinically not effective
Proportional Assist Ventilation –

Flow and/or volume

Instantaneous effort

normal

Disease

PAV

Proportional Assist Ventilation –

- Spontaneous breathing
  - $P_{mus} = Pres + Pel$
  - $P_{mus} = \sqrt{R_S} + V \times E_S$

Diagram:
- Flow and/or volume
- Instantaneous effort

Disease
- Normal
- PAV

Proportional Assist Ventilation –

1. Spontaneous breathing
   - \( P_{\text{mus}} = P_{\text{res}} + P_{\text{el}} \)
   - \( P_{\text{mus}} = \sqrt{\star} R_{\text{rs}} + V \times E_{\text{rs}} \)

1. Supported spontaneous breathing
   - \( P_{\text{mus}} + P_{\text{aw}} = P_{\text{res}} + P_{\text{el}} \)
   - \( P_{\text{mus}} + P_{\text{aw}} = \sqrt{\star} R + V_{T} \times E \)

\[ P_{\text{mus}} = \sqrt{\star} R + V_{T} \times E - P_{\text{aw}} \]

Equation of motion
PAV application

\[ P = \sqrt{\dot{V}} \times R + V_T \times E \] 

\[ \sqrt{\dot{V}} \times (R - FA) + V_T \times (E - VA) \]

**Normal**
- \( R_{RS} = 2 \text{ mbar/L/s} \)
- \( E_{RS} = 10 \text{ mbar/L} \)

**COPD**
- \( R_{RS} = 10 \text{ mbar/L/s} \)
- \( E_{RS} = 10 \text{ mbar/L} \)
- \( \)
PAV application

\[ P = \sqrt{\dot{x}} \times R + V_T \times E \]
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COPD
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Example
Flow = 2 L/s
\[ V_T = 0.5 \text{ L} \]

Normal
\[ P_{mus} = \sqrt{\dot{x}} \times 2 + V_T \times 10 \]
9 mbar

Patient
\[ P_{mus} = \sqrt{\dot{x}} \times 10 + V_T \times 10 \]
25 mbar !!
**PAV application**

\[
P = \sqrt{\cdot} \times R + V_T \times E
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- \( P_{mus} = \sqrt{\cdot} \times 2 + V_T \times 10 \)
- 9 mbar

**Patient**
- \( P_{mus} = \sqrt{\cdot} \times 10 + V_T \times 10 \)
- 25 mbar !!

\( FA = 8 \text{ mbar/L/s}, \quad VA = 0 \text{ mbar/L} \)

\[
P = \sqrt{\cdot} \times (10 - 8) + V \times (10 - 0)
\]
PAV application

\[ P = \sqrt{\cdot} \times R + V_T \times E \]
\[ \sqrt{\cdot} \times (R-FA) + V_T \times (E-VA) \]

**Normal**
- \( R_{RS} = 2 \text{ mbar/L/s} \)
- \( E_{RS} = 10 \text{ mbar/L} \)

**ARDS**
- \( R_{RS} = 2 \text{ mbar/L/s} \)
- \( E_{RS} = 40 \text{ mbar/L} \)

**Example**
- Flow = 2 L/s
- \( V_T = 0.5 \text{ L} \)

**Normal**
- \( P_{mus} = \sqrt{\cdot} \times 2 + V_T \times 10 \)
- 9 mbar

**Patient**
- \( P_{mus} = \sqrt{\cdot} \times 2 + V_T \times 40 \)
- 24 mbar !!

\[ FA = 0 \text{ mbar/L/s}, \quad VA = 30 \text{ mbar/L} \]

\[ P_{mus} = \sqrt{\cdot} \times (2 - 0) + V \times (40 - 30) \]
PAV application

ADVANTAGES

• Effective unloading of WoB
• Adjust to patient demand
• Improves patient-ventilator synchrony
• No trigger delay/ineffective efforts

LIMITATIONS

• “runaway” phenomenon
• Relies on measurement of R and E (difficult in spontaneous breathing)
• Needs to be adjusted to changes in R and E
PAV – outcomes: sleep and

• Patient-ventilator interaction and sleep in mechanically ventilated patients: PAV vs. PS: 13 med-surg. Patients 22 days on MV, crossover.
  • PAV ↘ arousals from 16 to 9/h (p<0.02)
  • ↓ pat-vent. asynchrony
  • Arousals /h and asynchrony /h correlate with each other (p<0.005) and with WoB

Bosma K  Crit Care Med 2007; 35:1048–1054
PAV – outcomes: sleep and

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<thead>
<tr>
<th>Type of Asynchrony</th>
<th>PAV</th>
<th>PSV</th>
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<tr>
<td>Auto-triggering</td>
<td>5.4 ± 8.2</td>
<td>25.8 ± 42.3°</td>
</tr>
<tr>
<td>Ineffective triggering</td>
<td>11.6 ± 10.8</td>
<td>19.6 ± 31.8</td>
</tr>
<tr>
<td>Double triggering</td>
<td>5.8 ± 7.3</td>
<td>7.3 ± 6.8</td>
</tr>
<tr>
<td>Delayed cycling</td>
<td>0.6 ± 1.0</td>
<td>3.1 ± 4.6°</td>
</tr>
<tr>
<td>Total asynchronies</td>
<td>23.7 ± 15.4</td>
<td>52.9 ± 59.2°</td>
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PAV – outcomes: Mechanical ventilation and weaning

• PAV with load-adjustable gain factors (PAV+) vs. PS in critically ill patients: 208 pts, 36h mech vent., Randomized for 48h.
  • failure rate by 10% (OR 0.45)
  • pat-vent. Dyssynchrony (5.6 vs. 29%)
  • No difference in weaning success

Xirouchaki ICM 2008; 34:2026–2034
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Neurally Adjusted Ventilator

Neurally Adjusted Ventilator

NAVA – Application

Invasive ventilation

Noninvasive ventilation
NAVA – Application

Invasive ventilation

Noninvasive ventilation
NAVA – Application

Invasive ventilation

Noninvasive ventilation
NAVA – Application

Invasive ventilation vs Noninvasive ventilation
NAVA application

ADVANTAGES

• Effective unloading of WoB
• Adjust to patient demand
• In-/expiratory trigger
• Improves patient-ventilator synchrony
• No trigger delay/ineffective efforts

LIMITATIONS

• Additional enteral tube
• Trigger signal may be disturbed
NAVA – Outcomes
NAVA – Outcomes

- NAVA improves the quality of sleep over PSV in terms of REM sleep (17% vs. 5%), fragmentation index (16 vs. 40/h) and ineffective efforts (0 vs. 24/h) in nonsedated adult ICU pts. (n=14)
NAVA – Outcomes

- NAVA improves the quality of sleep over PSV in terms of REM sleep (17% vs. 5%), fragmentation index (16 vs. 40/h) and ineffective efforts (0 vs. 24/h) in non-sedated adult ICU pts. (n=14)

- NAVA improves patient–ventilator interaction in 22 pts. with ALI (P/F 190 mmHg) and asynchrony, ineffective efforts, trigger delay and auto-triggering, but increased RR and double triggering.

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• NAVA improves patient-ventilator interaction in 22 pts. with ALI (P/F 190 mmHg) and asynchrony, ineffective efforts, trigger delay and auto-triggering, but increased RR and double triggering.

• Neurally triggered breaths reduce trigger delay, improve ventilator response times, and may decrease work of breathing in children and during noninvasive ventilation.

Comparison NAVA vs. PAV

No comparative clinical studies available
Adaptive Support Ventilation –

Pressure control / assist mode
There is an optimum for $V_A$ to minimize work of breathing
- RR
- Tidal volume

$$V_A = \frac{KDf + K' \pi^2 D f^2 + 4K'' \pi^2 D^2 f^3}{K - 4K'' \pi^2 D f^2}$$
ASV – Outcomes

Sulzer CF et al. Anesthesiology 2001 Dec; 95: 1339–1345
Tassaux D, Critical Care Med 2002 Apr; 30: 801–807
ASV – Outcomes

• Several studies on weaning post cardiac surgery, only 1 (ASV vs. SIMV) showed ↓ mechanical ventilation 4 h (median)

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ASV – Outcomes

- Several studies on weaning post cardiac surgery, only 1 (ASV vs. SIMV) showed mechanical ventilation 4 h (median)
- ASV improves patient-ventilator interaction (vs. SIMV)
- Ventilation in ALI/ARDS is possible, but
  - Failure in 20% (Pinsp > 35 mbar)
  - 25% pts. $V_T > 8.8\text{ ml PBW}$
ASV application

ADVANTAGES

• Permits gradual withdrawal of mechanical ventilatory support
• ? Effect in reduced physician availability

LIMITATIONS

• Increases in tidal volume
• No proof of concept for underlying theorem (minimize WoB)
NeoGanesh (Smart Care™)

Patient Monitor
Alarms
Ventilator Control

Ventilator in PSV

RR, TV, EtCO₂

Input

Automated pressure support
Output
Automated Weaning

Automated Weaning System
Processing

Made in Créteil

JF Lellouche, Université Laval, QC
Example of Weaning with «SmartCare»

- Automated reduction of the PSV level
- Minimum level of PS
- PEEP must be ≤ 5 cmH₂O
- « Automated SBT »
- Message: « separation from ventilator »
## SmartCare – does it work?

<table>
<thead>
<tr>
<th>Outcome</th>
<th>CDW Group (n = 74)</th>
<th>Usual Weaning Group (n = 70)</th>
<th>p Value</th>
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<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>
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<tr>
<td>Hospital length of stay</td>
<td>30.00 (17.00–54.75)</td>
<td>35.00 (21.00–60.25)</td>
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<tr>
<td>Reintubation within 72 h</td>
<td>12 (16)</td>
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<td>Any reintubation</td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Complication</th>
<th>CDW Group (n = 74)</th>
<th>Usual Weaning Group (n = 70)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reintubation within 72 h</td>
<td>12 (16)</td>
<td>16 (23)</td>
<td>0.40</td>
</tr>
<tr>
<td>Any reintubation</td>
<td>17 (23)</td>
<td>22 (33)</td>
<td>0.20</td>
</tr>
<tr>
<td>Need for noninvasive ventilation</td>
<td>14 (19)</td>
<td>26 (37)</td>
<td>0.02</td>
</tr>
<tr>
<td>Self-extubation</td>
<td>8 (11)</td>
<td>7 (10)</td>
<td>0.00</td>
</tr>
<tr>
<td>Tracheostomy</td>
<td>12 (16)</td>
<td>13 (19)</td>
<td>0.83</td>
</tr>
<tr>
<td>Mechanical ventilation duration for &gt; 14 d</td>
<td>12 (16)</td>
<td>20 (29)</td>
<td>0.11</td>
</tr>
<tr>
<td>Mechanical ventilation duration for &gt; 21 d</td>
<td>5 (7)</td>
<td>11 (16)</td>
<td>0.11</td>
</tr>
</tbody>
</table>

SmartCare – does it work?

Randomized Controlled Trial
Medical patients
102 patients included

Number at risk
SmartCare/PS 51  19  9  7  4  4
Control 51       15 10  4  3  2

Rose L et al. Intensive Care Med 2008; 34:1788
Schaedler D. AJRCCM 2009;
SmartCare – does it work?

Randomized Controlled Trial
Medical patients
102 patients included

Number at risk
SmartCare/PS 51  19  9  7  4  4  4
Control 51  15  10  4  3  2  2

P=0.18
n=300

Rose L et al. Intensive Care Med 2008; 34:1788
Schaedler D. AJRCCM 2009;
SmartCare – does it work?

Randomized Controlled Trial
Medical patients
102 patients included

Total ventilation time

Subgroup Cardiac Surgery
P=0.037
n=131

Protocol
SmartCare/PS

Number at risk
SmartCare/PS 51 19 9 7 4 4
Control 51 15 10 4 3 2

Time to "Separation" (h)

Ventilated patients [%]

Total ventilation time [hours]

Rose L et al. Intensive Care Med 2008; 34:1788
Schaedler D. AJRCCM 2009;
WEAN Study

SmartCare – Outcomes

WEAN pilot study

Co-PI: K. Burns/F. Lellouche

RCT
PILOT/ FEASIBILITY
SmartCare vs written weaning protocols
8 Centers
Primary outcome: acceptance of weaning protocols
## OUTCOME DATA

<table>
<thead>
<tr>
<th>Variables</th>
<th>Protocol Weaning (n=43)</th>
<th>Automated Weaning (n=51)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to first extubation, days median (25-75)</td>
<td>4 (2-12)</td>
<td>3 (2-5)</td>
<td>0.02</td>
</tr>
<tr>
<td>Time to first successful extubation, days median (25-75)</td>
<td>5 (3-19)</td>
<td>4 (2-7)</td>
<td>0.10</td>
</tr>
<tr>
<td>Reintubation, n (%)</td>
<td>11 (25.5%)</td>
<td>9 (17.7%)</td>
<td>0.35</td>
</tr>
<tr>
<td>Patients with prolonged ventilation (&gt;21 days), n (%)</td>
<td>6 (18.2%)</td>
<td>0</td>
<td>0.01</td>
</tr>
<tr>
<td>Ever had tracheostomy, n (%)</td>
<td>15 (34.9%)</td>
<td>8 (16%)</td>
<td>0.04</td>
</tr>
<tr>
<td>Total duration of intubation, days median (25-75)</td>
<td>10.5 (8, 17.5)</td>
<td>12 (6, 25)</td>
<td>0.37</td>
</tr>
<tr>
<td>Duration of ICU stay, days median (25-75)</td>
<td>9 (5, 25)</td>
<td>7 (5, 14)</td>
<td>0.13</td>
</tr>
<tr>
<td>Duration of Hospitalization, days median (25-75)</td>
<td>31.5 (16, 49.5)</td>
<td>22 (14, 33)</td>
<td>0.19</td>
</tr>
<tr>
<td>ICU death, n (%)</td>
<td>9 (20.9%)</td>
<td>9 (17.7%)</td>
<td>0.69</td>
</tr>
</tbody>
</table>

### Kaplan-Meier Curves for Days to Successful Extubation

- **AW**
  - Number of Patients: 47
  - Successful Extubation: 40 (85.1%)
  - Log Rank P-value: 0.0105

- **PW**
  - Number of Patients: 43
  - Successful Extubation: 35 (79.17%)
  - Log Rank P-value: 0.1315
Conclusions
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• New modes of ventilation provide better synchrony and have the potential to shorten the weaning phase with less physician attendance
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• Factors unclear: Who, When, how?
Thank you!

Department of Anesthesia