CLOSED LOOP SYSTEMS IN MECHANICAL VENTILATION

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Points to be covered

• Introduction
• Advantages of Closed Loop systems
• Prerequisites
• Description of Various Modes
• Do they translate into clinical benefit?
• Conclusions
What are closed loop systems?
Types of Ventilator Control systems

1. Open Loop system
2. Closed Loop system (feedback control system)
Open Loop system

INPUT (Settings for desired Pressure, Volume or Flow)

Controller (Ventilator)

Disturbances (Leaks, ET Block, erratic patient effort)

Controlled system (Patient)

OUTPUT (Actual pressure, volume, flow delivered)
Open Loop system

• Simple, cheap and *stable* System…

BUT

• No feedback from patient to compare with desired settings
• Hence cannot take into account disturbances
• Cannot correct its own output → Has to be changed manually
• Eg. Conventional modes – ACMV (PCV/VCV), PSV, SIMV
Closed Loop system

• A system where the measured output has an effect upon the input quantity in such a manner as to maintain the desired output

• Loop becomes closed by introducing
  a) Sensors for various parameters
  b) Feedback pathway
  c) Comparator
**Closed Loop system**

**INPUT** (Settings for desired Pressure, Volume or Flow)

Comparator

Error Signal

Controller (Ventilator)

Controlled system (Patient)

Sensors eg. Pressure, Volume, Flow

Feedback Signal

Disturbances (Leaks, ET block, Erratic patient efforts)

OUTPUT (Actual pressure, volume, flow delivered)
Comparison with Open Loop Systems

**Open Loop**
- All settings need to be set manually
- Output needs to be monitored frequently and settings changed accordingly
- Cheap, simple, stable
- Asynchrony

**Closed Loop**
- Some settings are automatically adjusted as per monitored parameters
- Takes into account disturbances too and makes corrective action
- Sophisticated and hence costly
- Better synchrony
What parameters to close the loop?

- Accurate
- Reproducible
- Technology integrated in ventilator
- Not very expensive
- Non-invasive
What parameters to close the loop?

A. Patient effort – Respiratory muscle support
   • Flow, Resp Rate, Diaphragmatic EMG

B. Ventilation
   • Expiratory time constant, ETCO$_2$

C. Oxygenation
   • SpO$_2$
Anticipated Benefits

- Rapidly adapts ventilation to the lung condition – more physiological
- Increases safety
- Better ventilator-patient synchrony
- More patient comfort, less need for sedation/paralysis
- Decreases weaning duration
- Decreases workload on doctors, nurses
- Liberates clinicians from simple tasks → Can concentrate on complex time consuming patients
- Decreases false alarms..
Classification based on Levels of autonomy (and complexity!)

1. Manual – All targets set manually – No autonomy to ventilator
   Eg. ACMV, PSV, PCV, SIMV

2. Servo control – Target changes depending on patient effort
   Eg. ATC, PAV, NAVA

3. Automatic Control – Ventilator decides targets based on
   mathematical models or Artificial Intelligence
   Eg. MMV, ASV, SmartCare, Volume Support

                   Closed Loop Systems
<table>
<thead>
<tr>
<th>Manufacturer’s Mode Name</th>
<th>Autonomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume Control Ventilation Assist/Control</td>
<td>Manual</td>
</tr>
<tr>
<td>Pressure Control</td>
<td>Manual</td>
</tr>
<tr>
<td>Synchronized Intermittent Mandatory Ventilation</td>
<td>Manual</td>
</tr>
<tr>
<td>Pressure Controlled Synchronized Mandatory Ventilation</td>
<td>Manual</td>
</tr>
<tr>
<td>Spontaneous/Timed Ventilation</td>
<td>Manual</td>
</tr>
<tr>
<td>Pressure Support Ventilation</td>
<td>Manual</td>
</tr>
<tr>
<td>Intermittent Positive Pressure Ventilation With Pressure Limited</td>
<td>Manual</td>
</tr>
<tr>
<td>Volume Control</td>
<td>Manual</td>
</tr>
<tr>
<td>Volume Control Assist Control With Machine Volume</td>
<td>Manual</td>
</tr>
<tr>
<td>Synchronized Intermittent Mandatory Ventilation With Pressure Limited</td>
<td>Manual</td>
</tr>
<tr>
<td>Automatic Tube Compensation</td>
<td>Servo</td>
</tr>
<tr>
<td>Proportional Assist Ventilation Plus</td>
<td>Servo</td>
</tr>
<tr>
<td>Proportional Pressure Support</td>
<td>Servo</td>
</tr>
<tr>
<td>Neurally Adjusted Ventilatory Assist</td>
<td>Servo</td>
</tr>
<tr>
<td>Assist/Control (Adaptive Flow and I-Time)</td>
<td>Automatic</td>
</tr>
<tr>
<td>Pressure Regulated Volume Control</td>
<td>Automatic</td>
</tr>
<tr>
<td>Volume Controlled Synchronized Mandatory Ventilation (Adaptive Flow and I-Time)</td>
<td>Automatic</td>
</tr>
<tr>
<td>Mandatory Minute Volume Ventilation</td>
<td>Automatic</td>
</tr>
<tr>
<td>AutoMode (PRVC - VS)</td>
<td>Automatic</td>
</tr>
<tr>
<td>Volume Support</td>
<td>Automatic</td>
</tr>
<tr>
<td>Mandatory Rate Ventilation</td>
<td>Automatic</td>
</tr>
<tr>
<td>Adaptive Support Ventilation</td>
<td>Automatic</td>
</tr>
<tr>
<td>SmartCare/PS</td>
<td>Automatic</td>
</tr>
</tbody>
</table>
Common Commercially available modes

- Controlled mode
- Assisted mode
- Spont mode
  - PAV
  - NAVA
  - SmartCare
  - Adaptive Support Ventilation
  - IntelliVent®
Servo Modes

• Term “servo” coined by Joseph Farcot in 1873 to describe steam-powered steering systems.
• Later, hydraulic “servos” were used to position anti-aircraft guns on warships.
• Servo control converts a small mechanical motion into one requiring much greater power, using a feedback mechanism.
• Similar to “Power Steering” in Cars!
• High level of patient ventilator synchrony
• Ventilator output closely matches patient demand
Automatic Tube Compensation (ATC)

Principle

• Narrowest part of circuit = ET tube
• Hence there is a pressure drop across ET = ΔP
• This amount of pressure required to overcome ET resistance
• ET resistance not constant → Proportional to Flow
• Hence ΔP too not constant → Proportional to Flow generated by patient (i.e. Patient demand)
• Patient demand and flow rate varies breath by breath and patient to patient
Pressure–Flow relationship in ET tube
Conventional PSV (without ATC)

- In PSV without ATC → Regardless of patient demand → Same Pressure applied (IPAP) to each breath
- However we don’t know what portion of pressure applied is lost in overcoming tube resistance
- 3 scenarios arise:
  1) at low flow rates, PSV overcompensates for tube resistance
  2) at medium flow rates, PSV compensates for tube resistance
  3) at high flow rates, PSV undercompensates for tube resistance
Conventional PSV (without ATC)
ATC

• Analyses the flow across ET during each instant and decides Pressure Compensation based on the curve
• Hence ATC $\rightarrow$ Non-linear flow dependent Pressure Support
• Present in:
  • Drager Evita 4 and XL, Viasys Avea, Hamilton Galileo
• Inputs required
  • Type of tube (ET vs tracheostomy)
  • Inner diameter of tube
  • % compensation required (0-100%)
Clinical Benefit? - Controversial

- Basically → Alternate weaning strategy
- Theoretically decreases WoB and gives better patient comfort
- Failure of SBT in ATC mode compared to PSV may have better predictive value for extubation failure (NPV 83% vs 56%)
- May shorten weaning process in children
- However several RCTs in adults failed to show it is better than PSV/T-piece in shortening weaning, or better predicting successful weaning.
Neurally Adjusted Ventilatory Assist (NAVA)
NAVA

• Developed by Maquet in 2006, available only in Servo
• Esophageal catheter with electrodes placed to record diaphragmatic EMG (Edi)
• EMG signal is amplified into inspiratory Paw
• Amount of amplification decided by gain factor - “NAVA level”

\[ P_{peak} = NAVA \text{ level} \times (Edi_{peak} - Edi_{min}) + PEEP \]
• Set by clinician based on patient’s ventilatory demand
• Hence main principles of NAVA:
  a. Triggering is at diaphragmatic level
  b. Pressure support during each breath proportional to EMG signal
NAVA – Schematic Diagram
EMG (uV)

Gain Factor (cmH20/uV)
Insertion of Esophageal Catheter

• Similar to NG tube – In fact esophageal catheter acts as feeding tube
• Size 6 Fr – 16 Fr (usually 16F, 125 cm length for adults)
• Insertion length according to formula provided in catheter package
• Test Edi Module and Connect Edi Cable to Edi Catheter
• Check catheter position: using ECG waveform from the electrodes in the catheter
• Fix like Ryle’s tube
Setting NAVA level

• Put patient in conventional mode (PSV/PCV), Select “NAVA preview”

• Two pressure curves appear
  • Yellow, represents the actual pressure delivery
  • Gray, provides estimation of pressure delivered (based on actual Edi and NAVA level) if patient were switched to NAVA at this time

• Adapt NAVA level so that area under the estimated pressure curve (gray) resembles area under the actual pressure curve (yellow)

• Usual level is 0.5 to 3 cmH2O/uV

• Weaning → Reduce by 0.2 cmH2O/uV at a time
<table>
<thead>
<tr>
<th>Authors</th>
<th>Group</th>
<th>Study design</th>
<th>Duration</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colombo and colleagues, 2008</td>
<td>Acute respiratory failure(n = 14)</td>
<td>Crossover study – NAVA vs PSV set to obtain VT 6 to 8 ml/kg</td>
<td>20 minutes x 3</td>
<td>NAVA averted the risk of overassistance and improved synchrony</td>
</tr>
<tr>
<td>Wu and colleagues, 2009</td>
<td>ARDS (n = 18)</td>
<td>PSV vs. NAVA – randomized study. Incremental PSV and NAVA adjusted in 4 steps</td>
<td>5 minutes x 4</td>
<td>Improved synchrony with NAVA</td>
</tr>
<tr>
<td>Brander and colleagues, 2009</td>
<td>Acute respiratory Failure (n = 15)</td>
<td>NAVA level increased progressively and Edi measured for next 3 hrs</td>
<td>3 hours</td>
<td>Progressive implementation of NAVA may be a method for determining the adequate level – downregulation of Eadi Confirmed</td>
</tr>
<tr>
<td>Schmidt and colleagues, 2010</td>
<td>Acute lung injury (n = 12)</td>
<td>Longitudinal observational study – NAVA vs. PSV with increasing assist</td>
<td>10 minutes x 4</td>
<td>NAVA increases breathing pattern variability</td>
</tr>
<tr>
<td>Coisel and colleagues, 2010</td>
<td>Postop patients (n = 15)</td>
<td>Crossover randomized – NAVA vs. PSV.</td>
<td>24 hours</td>
<td>Variability of, tidal volume and minute ventilation were signifi cantly higher with NAVA than with PSV. Variability of electrical diaphragmatic activity was signifi cantly lower with NAVA than with PSV. Oxygenation increased with NAVA</td>
</tr>
<tr>
<td>Terzi and colleagues, 2010</td>
<td>ARDS (n=11)</td>
<td>Crossover randomized – NAVA vs. PSV</td>
<td>5 minutes x 4 x 3 = 60 minutes</td>
<td>Compared with PSV, NAVA limited the risk of overassistance, prevented patient–ventilator asynchrony, and improved overall patient–ventilator interactions. Compared with the pneumatic trigger, NAVA signifi cantly decreased patient–ventilator asynchrony</td>
</tr>
<tr>
<td>Spahija and colleagues,2010</td>
<td>COPD (n=14)</td>
<td>Prospective, comparative crossover – NAVA vs PSV</td>
<td>10 minutes x 2</td>
<td>NAVA improved patient–ventilator synchrony by reducing the triggering and cycling delays, especially at higher levels of assist, while preserving breathing and maintaining blood gas exchange</td>
</tr>
<tr>
<td>Passath and colleagues, 2010</td>
<td>Unselected patients (n=20)</td>
<td>Longitudinal observational study. Evaluation of effects of PEEP on breathing pattern and neuroventilatory efficiency during NAVA.</td>
<td>20 minutes x 3</td>
<td>During NAVA, increasing PEEP reduces respiratory drive. Patients adapt their neuroventilatory efficiency such that the individual ventilatory pattern is preserved over a wide range of PEEP levels. Monitoring VT/EAdi during PEEP changes allows identification of a PEEP level at which tidal breathing occurs at minimal EAdi cost</td>
</tr>
<tr>
<td>Piquilloud and colleagues, 2011</td>
<td>Unselected patients (n = 22; COPD n = 8/22)</td>
<td>Prospective interventional study – three consecutive periods of ventilation: PSV–NAVA–PSV.</td>
<td>20 minutes x 3</td>
<td>NAVA reduces trigger delay, improves expiratory synchrony and reduces total asynchrony events</td>
</tr>
<tr>
<td>Roze and colleagues, 2011</td>
<td>Unselected patients (n = 15)</td>
<td>To determine feasibility of daily titration of NAVA level in relation to diaphragmatic electrical activity measured during a PSV SBT</td>
<td>Until extubation</td>
<td>Daily titration of NAVA level with an electrical goal of 60% EAdimaxSBT is feasible and well tolerated</td>
</tr>
</tbody>
</table>
Potential Benefits

• Improved Synchrony
  • Patient comfort - Providing correct amount of assistance required
  • Better sleep
  • Less V/Q mismatch, decreased O2 requirements

• No influence of Auto-PEEP on triggering

• Edi - Unique monitoring tool to assess
  • Respiratory drive
  • Volume requirements
  • Indications for sedation and weaning – Edi amplitude and Ventilatory assistance decrease as patient improves
  • Assess diaphragm atrophy

• Esophageal ECG
Figure 1. Example of recording during neurally adjusted ventilatory assist and pressure-support ventilation. (a) Neurally adjusted ventilatory assist using the neural trigger: no asynchrony was observed. (b) Pressure-support ventilation: wasted efforts are underscored. Each wasted effort is identified by a blue rectangle.
Contraindications

• Known contraindications for naso-/orogastric feeding tube (recent upper airway surgery, esophageal surgery, recent esophageal bleeding, skull base fracture)

• Known phrenic nerve lesions

• Congenital myopathy (relative contraindication)

• MRI scanning: the Edi Catheter not approved for use in MRI environments (Remove from patient before entering MRI area)

• Main Limitations → INVASIVE, EXPENSIVE
Does it improve patient outcomes?

• NAVA – Exciting concept given the physiological advantages!
• Whether Physiological benefits translate into better patient outcomes? – Remains to be seen
• As of now, no studies comparing mortality, morbidity and duration of ICU stay
Proportional Assist Ventilation

• First described in 1992 by Younes et al

• Available in Drager Evita XL, Puritan Bennett 840

• PAV is a form of PSV, in which inspiratory airway pressure (Pinsp) within each breath is titrated by the ventilator in proportion to the patient’s inspiratory airflow, which is used as a surrogate of the patient’s respiratory muscle effort

• Level of amplification decided by:
  a. Lung mechanics – Resistance/compliance
  b. Chosen level of assistance (0-100%)
Fig. 5. Control circuit for a servo targeting scheme (e.g., Proportional Assist Ventilation). The controller is designed so that inspiratory pressure as a function of time ($P(t)$) is proportional to both volume as a function of time ($V(t)$) and flow as a function of time ($\dot{V}(t)$). The constant of proportionality $K_1$ represents the amount of elastance to be supported. The constant of proportionality $K_2$ represents the amount of resistance to be supported.
Comparison of Flow-Time curves

Paw

Pressure Support, PACV, SMV

Paw

PAV

EADi

NAVA
Gain Setting

• The proportionality between flow and Paw,insp is determined by a “gain setting”, which is adjusted by clinician
• Gain based on the patient’s respiratory mechanics, resistance (Rrs) and compliance (Crs) of the respiratory system
• To use PAV correctly, Rrs and Crs should be evaluated continuously and the Gain adjusted accordingly
• This setting determines the proportion of the total work of breathing that will be done by the ventilator
ADVANTAGES

• Adapts to Ventilatory demand and load of patient
• Better patient synchrony and comfort
• Greater breath-to-breath variability allowing more physiological breathing
• Better Sleep and less awakenings

DISADVANTAGES

• Complexity
• Resistance, Compliance has to be estimated
• Lung mechanics may change over hours – Rrs and Crs have to be frequently monitored and entered
• If Gain setting not optimal → Instability
• There should be no leaks
Variations

A. Drager Evita XL – “Proportional Pressure Support”
   Both elastance and resistance manually entered by clinician
   ATC also available – but level of compensation set manually

B. Puritan Bennett 840 – “PAV +”
   Ventilator itself calculates Elastance and Compliance continuously
   ATC level too set automatically
   Gain values better estimated – Less Instability
   Decreases number of Manual adjustments
   Adapts to changing lung mechanics
Automatic Modes

- ASV
- SmartCare
- IntelliVent
Adaptive Support Ventilation

MV = Minute Ventilation
Principle

Based on equation given by Otis in 1950
For given MV, WoB optimum at a particular frequency
In ASV MV target is set as % of ideal MV
100% MV taken as 0.1 l/kg IBW
Ventilator itself delivers required Pressure to maintain the MV based on feedback from patient

\[
f = \frac{V_d}{a \times RC} - 1
\]

\[
1 + 2a \times RC \times \frac{\text{Min Vol} - (f \times V_d)}{V_d}
\]
The ASV Target Curve

Baro/VoluTrauma

AutoPEEP
**Settings**

To be set Manually
1. IBW
2. %MV
3. fiO2
4. PEEP
5. Pressure limit
6. Rate limit
7. Slope of pressurisation (Pramp)
8. Flow Trigger (2-3l/m)
9. Expiratory Trigger Sensitivity (25%)

Continuous analysed by Ventilator
1. Ppeak
2. Vt
3. RR
4. RC exp
5. Compliance

Automatically adjusted by Ventilator
1. Pinsp
2. I:E
3. Flow rate
4. RR (inactive patient)
MV Settings

- Normal 100%
- Asthma 90%
- Acute respiratory distress syndrome (ARDS) 120%
- Others 110%
- Add 20% if T body >38.5°C (101.3°F)
- Add 5% for every 500 m (1640 feet) above sea level
Working

- ASV operates in a closed loop to move closer to the minute ventilation target
- Automatically adjust the inspiratory pressure, the I/E ratio, and the respiratory rate (in the absence of cycles triggered by the patient) to achieve this objective
- Can theoretically be used from the initiation of mechanical ventilation in patients who make no respiratory effort to weaning phase when patient triggers all cycles, since this mode can deliver all cycles - controlled/assisted/spontaneous
### Follow-up

<table>
<thead>
<tr>
<th>Condition</th>
<th>Adjustments % Min Vol</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABG Normal</td>
<td>None</td>
<td>Check respiratory pressures</td>
</tr>
<tr>
<td>High PaC02</td>
<td>Increase % Min Vol</td>
<td></td>
</tr>
<tr>
<td>Low PaC02</td>
<td>Lower % Min Vol</td>
<td>Check mean Pressure and oxygentacion</td>
</tr>
<tr>
<td>High respiratory drive</td>
<td>Consider increase % Min Vol</td>
<td>Consider sedation</td>
</tr>
<tr>
<td>Low 02 saturation</td>
<td>None</td>
<td>Consider increase PEEP or FiO2</td>
</tr>
</tbody>
</table>
## Advantages and Disadvantages

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Versatile and extremely safe to use</td>
<td>Does not allow direct programming of VT, RR and I:E ratio</td>
</tr>
<tr>
<td>Ventilate virtually all intubated patients actively or passively</td>
<td>Limited experience in pediatric patients</td>
</tr>
<tr>
<td>Prevents tachypnea, auto-PEEP and dead space</td>
<td>Operation algorithm tends to ventilate with low VT and high RR</td>
</tr>
<tr>
<td>Less need of human manipulation of the machine</td>
<td>Only available in Hamilton ventilators</td>
</tr>
<tr>
<td>Decreased time on the mechanical ventilation</td>
<td></td>
</tr>
<tr>
<td>Adjusts to patient respiratory effort</td>
<td></td>
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</tbody>
</table>

**VT:** Tidal volume; **RR:** Respiratory rate; **auto-PEEP:** Auto-positive end-expiratory pressure; **I:E:** Inspiratory:Expiratory
# Ventilation delivered in various settings

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>COPD</th>
<th>Chest wall restriction</th>
<th>ARDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days/patients</td>
<td>706/140</td>
<td>217/40</td>
<td>54/13</td>
<td>136/36</td>
</tr>
<tr>
<td>RC exp (sec)</td>
<td>0.78</td>
<td>1.13*</td>
<td>0.41*</td>
<td>0.55*</td>
</tr>
<tr>
<td>Vt/PBW (ml/kg)</td>
<td>8.3</td>
<td>9.4*</td>
<td>7.1*</td>
<td>7.6*</td>
</tr>
<tr>
<td>RR</td>
<td>17</td>
<td>16</td>
<td>23*</td>
<td>20*</td>
</tr>
<tr>
<td>I:E</td>
<td>0.5</td>
<td>0.4*</td>
<td>0.5</td>
<td>0.63*</td>
</tr>
</tbody>
</table>

*P-value <0.05

 Arnal et al Intensive Care Medicine 2008
Ventilation delivered in various settings

*P-value <0.05

Arnal et al Intensive Care Medicine 2008
ASV in ARDS

• Study of 108 patients*
  • Delivered Vt ~ 6 ml/kg IBW
  • Achieves Same Pplat (<30) as that in ARDS-Net Protocol
  • Delivers Lower Vt and Pplat depending on the case severity
    *Sulemanji et al, Anesthesiology, 2009

• Study of 51 patients*
  • Vt ~ 6 ml/kg
  • Pplat < 28
    *Arnal et al, AJRCCM, 2007
ASV in Weaning

<table>
<thead>
<tr>
<th>Study</th>
<th>Number of patients</th>
<th>Hours of MV Control (PSV)</th>
<th>Hours of MV (ASV)</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sultzer et al, 2001</td>
<td>36</td>
<td>4</td>
<td>3.2</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>Petter et al, 2003</td>
<td>34</td>
<td>3.2</td>
<td>2.7</td>
<td>NS</td>
</tr>
<tr>
<td>Gruber et al, 2008</td>
<td>48</td>
<td>8</td>
<td>2.7</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Dongelmans et al, 2009</td>
<td>121</td>
<td>16.3</td>
<td>16.2</td>
<td>NS</td>
</tr>
</tbody>
</table>
ASV in COPD

Kirakli et al, Eur Resp J, 2003
Intellivent
Intellivent

- Claimed to be First complete Closed Loop system
- Only 3 parameters need to be entered
  - PEEP
  - fiO2
  - %MV
- Based on EtCO2 and SpO2 – Even these parameters maybe automatically controlled!
NeoGanesh (SmartCare)

- Knowledge based Weaning System
- Basically an “Intelligent” form of PSV
- Principles:
  1. to maintain the patient in a respiratory ‘comfort zone’ by adapting the level of pressure support
  2. to gradually decrease the level of the pressure support in case of stability
  3. to implement automated spontaneous breathing trials (i.e. weaning tests) performed with minimal levels of pressure support, this last phase being followed by a message on the screen if those tests are positive.
Automated Weaning (NéoGanesh/SmartCare™):
1) Automated Adaptation of the level of PS
2) Automated Weaning Protocol
   - Automated decrease of the level of PS
   - Automated spontaneous breathing trials
   - Message displayed when automated SBTs are positive
     (« consider separation »)
Multicentre study of SmartCare

- Five academic centres recruited 144 patients in 1 year
- Patients included as soon as they could tolerate PSV and met criteria for early weaning
- 74 patients ventilated with SmartCare system, and 70 were weaned through usual care
- With the automated weaning system the weaning duration was reduced from a median of 4 days to 2 days (P 0.02)
- Total duration of mechanical ventilation was reduced from 12 to 7.5 days (P 0.003).
- Median duration of ICU stay was reduced from 15.5 to 12 days (P 0.02)
- Proportion of patients requiring non-invasive ventilation after extubation was reduced from 37% to 19% (P 0.02)
- The proportion of patients requiring mechanical ventilation for more than 21 days was 7% with the automated system weaning versus 16% (p 0.11)

Lellouche et al, AJRCCM 2006
Conclusion

• In future → Ventilators will adapt themselves to the patient and not the other way round
• Can significantly help in decision making and reducing work burden on ICU staff
• Patient comfort, weaning time, intubation time all may be decreased
• However the newer modes have to give solid proofs of their usefulness
• Clinicians have to use critical thinking on their part to separate the real innovations from “gimmicks” and evaluate their usefulness…