Automated Weaning

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VTA 2019

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What does *wean* mean?

- Extubation?
- Gradual reduction of ventilatory support?
- Both?

What I mean by *wean*

- Planned
  graded
  progressive
  reduction
  of ventilatory support
- Aim : make patient liberatable from ventilator

- Separate pre-extubation checklist.

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The bottom line...

Machines might do it better than humans.

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for loans of equipment and educational support

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Should we wean?

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Often…

- No.

- Operating Theatre Practice:
  - Short-term ventilation of healthy lungs
  - No time for lung / respiratory muscle changes
  - **Just pull out ETT at end of anaesthetic!**

- Overnight ventilation similar.

Long term ventilation

- Debilitates respiratory system
  - VILI, VIDD, muscle atrophy, neuropathy, ICUAW…
- Transition over time *might* be needed:
  - **From** : Machine does all the work.
  - **To** : Patient does all the work.
- **Time** to **train** up detuned respiratory muscles
  - **Progressive loading**
- **Time** to **stabilize** lung mechanics as load changes.

Evidence Based Confusion

- No published evidence supports weaning.
- “When the need for ventilation is ended, an SBT should be done. If successful, extubate.”
- True, in Operating Theatre.
- ICU?

Why the confusion?

- Many published trials date back 30 years
  - EBM based on what is published.
- "Insensitive" ventilators (*eg* VCV only)

- 1988 "Weaning" Algorithm:
  - REPEAT
    - SEDATE TO OBLIVION
    - VOLUME CONTROL 24h
    - T-PIECE TRIAL
  - UNTIL PASSES T-PIECE OR DIES

- Now we have ventilators that can interact…
- Now we *can* wean : but danger is going too slowly.

So how do we wean?

Example : My typical protocol

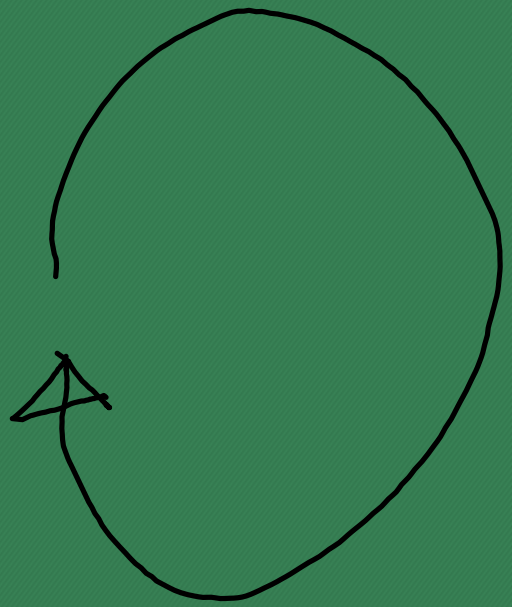
- Pressure Control
- Pressure Assist
  - Allow spontaneous triggers
- Pressure Support
- Progressively reduce pressures
- Extubate when on low pressure
  - ROMSHA passed

A protocol is like a computer program.

It is the implementation of an ALGORITHM.

At every step: “Loop closure”

- Target
- Plan
- Run
- **Check**
- **Adjust**
- **Recheck**
- (Replan)
- (Retarget)



One barrier to effective weaning

- Needs supervision.
- Needs active clinician involvement.
  - Clinicians must **check-adjust-recheck**
- Things happen
  - Backward steps occur
  - Clinicians often slow to regain ground
- **Humans are not good at consistent loop closure.**

Humans have to close all the loops

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Strengths and weaknesses

Humans

- Think

- Inconsistent
- Don’t follow programs
- Lazy

Machines

- Don’t think

- Consistent
- Follow programs
- “Inexorable”

For efficient weaning:

Humans **Should plan**

- Think
- Inconsistent
- Don’t follow programs
- Lazy

Machines **Should implement**

- Don’t think
- Consistent
- Follow programs
- “Inexorable”

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Philosophy of algorithms and protocols

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Protocols for all *vs* N = 1

- Tobin : “medicine must be individualized”
  - “Can never be protocolized”
- But all clinicians actually follow regular systems
  - *eg* measure vital signs to assess stability
- *All clinicians have their own algorithms that they apply to all their patients.*
  - Some algorithms are better than others
    - Number of inputs considered
    - How inputs are processed
    - How outputs are generated.

Why say protocols are bad?

- A protocol is an enforced algorithm.
  - A guideline is a recommended algorithm.

- If an algorithm was perfect
  the protocol would be too.

- Medical algorithms are not yet perfect
  as we don’t yet understand how bodies work.

Considerations for a weaning algorithm

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Some things don't work

Synchronized Intermittent Mandatory Ventilation

Shown to *slow* the wean.

1. **Neurological chaos** inflicted by 2 different breath types and timing restrictions

   Only discovered after mode was invented

2. **Nothing to push** the patient on

   Mandatory breaths, *unless progressively reduced*, give patient no reason to increase spontaneous breaths

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Some things we don't know

My algorithm:

- Pressure Support, progressively reduced
  - If VT adequate with low RR, reduce PS further
  - If VT increased with **higher RR** … ??
    - Increase PS ? … Tachypnoea => excess WoB ??
      - ? Need better tools to decide
        - Ptp measurement to measure WoB?
        - PAV+ on PB980 to proportionately offload WoB?
        - *Clinical check?*
- **Planned** rest periods? **Planned** variable intensity?

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In short…

- Writing algorithms for weaning is difficult.
  - Even if it is a guideline for nursing stff
- Thus designers have to “cop out”
  - Invoke and allow random human input to fix breaks in algorithm.
- So give machine algorithms some slack if they aren’t perfect yet.

Machine algorithms for weaning

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Selected ones

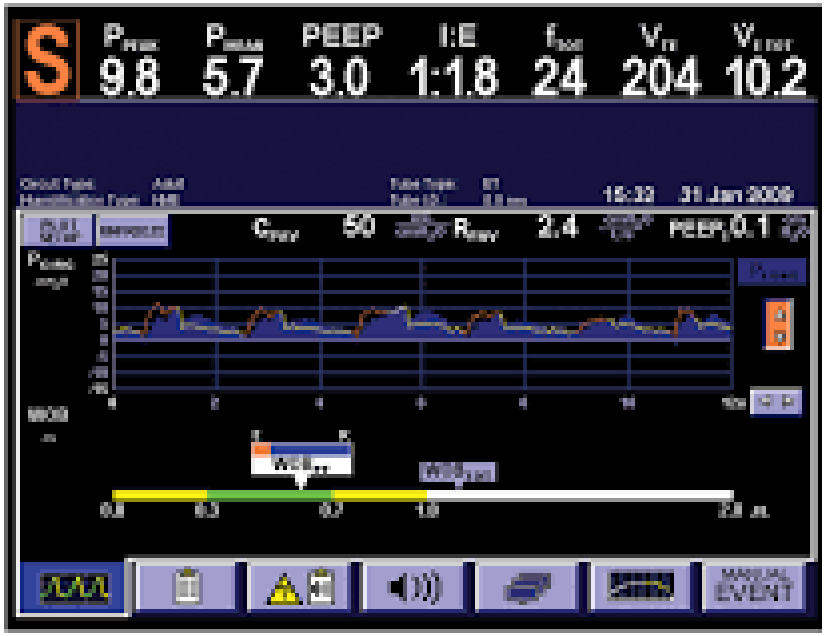
- (PAV+)
- Dräger SmartCare ®
- Adaptive Support Ventilation ® / AVM / AMV
- Intellivent ®

PAV+

- Proportional Assist Ventilation +
- Nellcor Puritan Bennett NP980 only.
- Not a closed-loop mode
  - But could be made into one?
- In Pressure Support :
  - algorithm quantifies Total Work of Breathing
  - Offloads a clinician- set percentage
  - This can be progressively reduced
  - Gets over guesswork as to how much PS

Matching support to workload: PAV+

The work of breathing bar shows total work of breathing (WOB_{TOT}) and patient work of breathing (WOB_{PT}).



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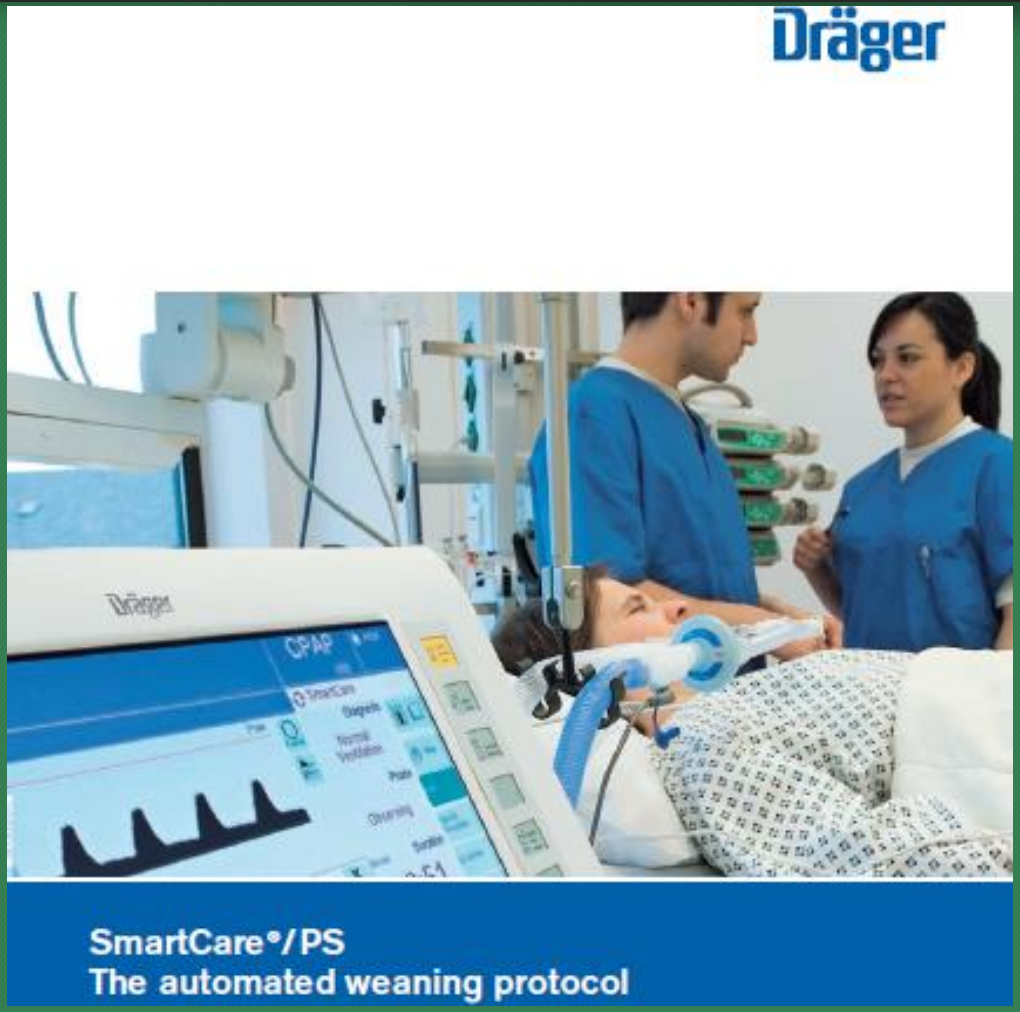
Dräger SmartCare/PS



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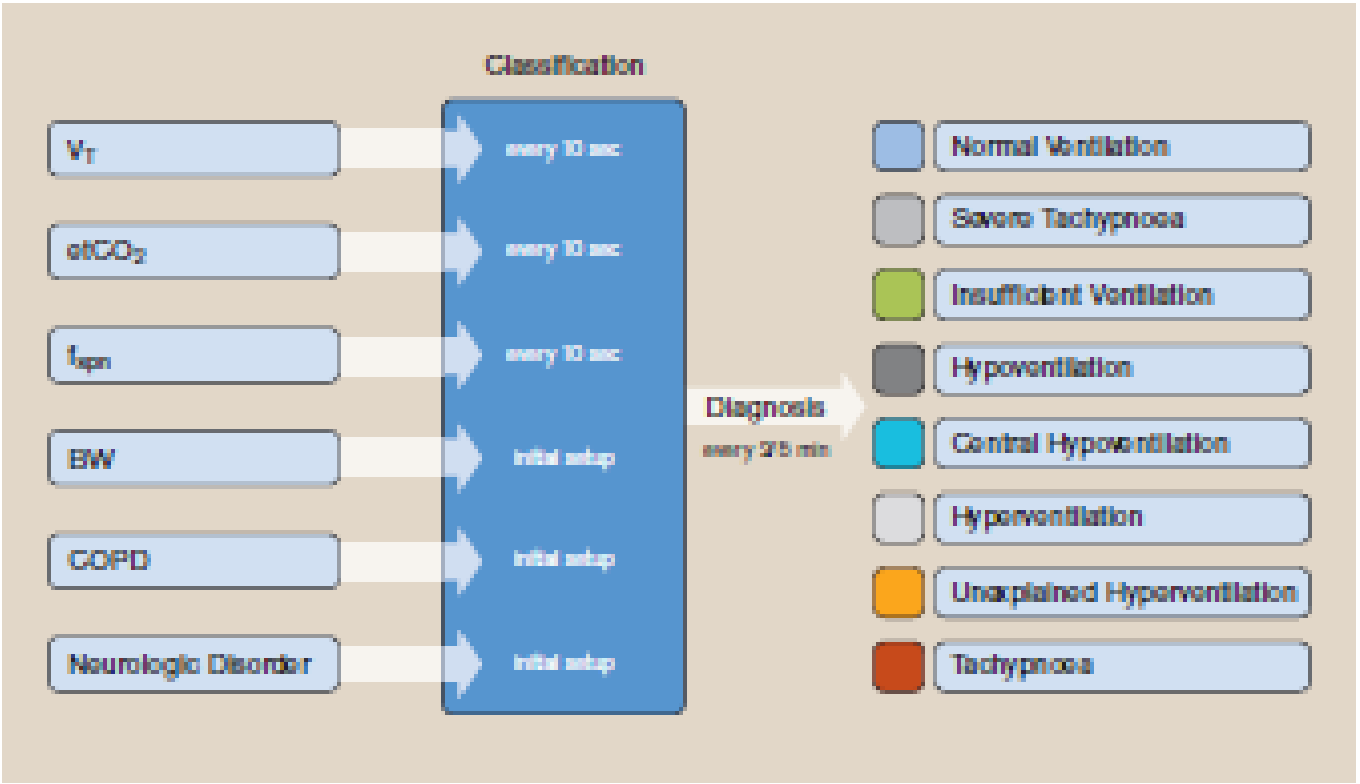
Automated adjustment Pressure Support

PATIENT MUST BE SPONTANEOUSLY BREATHING!



Uses $PetCO_2$

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PS adjustment…

Diagnosis	f_{spn}	V_T	$etCO_2$	PS
Hypoventilation	$f_{spn} < f_{spn}$ low	V_T low ≤ V_T	$etCO_2$ high ≤ $etCO_2$	will be increased
Severe tachypnea	f_{spn} max. ≤ f_{spn}	V_T low ≤ V_T	20 mmHg ≤ $etCO_2$	will be increased
Insufficient ventilation	f_{spn} low ≤ $f_{spn} < f_{spn}$ max.	–	$etCO_2$ high ≤ $etCO_2$	will be increased
	f_{spn} low ≤ f_{spn}	$V_T < V_T$ low	–	will be increased
Tachypnea	f_{spn} high ≤ $f_{spn} < f_{spn}$ max.	V_T low ≤ V_T	20 mmHg ≤ $etCO_2$ < $etCO_2$ high	will be increased
Central hypoventilation	$f_{spn} < f_{spn}$ low	$V_T < V_T$ low	$etCO_2$ high ≤ $etCO_2$	no change
Unexplained hyperventilation	f_{spn} high ≤ f_{spn}	V_T low ≤ V_T	$etCO_2$ < 20 mmHg	no change
Normal ventilation	f_{spn} low ≤ $f_{spn} < f_{spn}$ high	V_T low ≤ V_T	$etCO_2 < etCO_2$ high	will be reduced, weaning
Hyperventilation	$f_{spn} < f_{spn}$ low	–	$etCO_2 < etCO_2$ high	will be reduced

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Does Dräger Smartcare/PS work?

A Multicenter Randomized Trial of Computer-driven Protocolized Weaning from Mechanical Ventilation

François Lellouche, Jordi Mancebo, Philippe Jolliet, Jean Roeseler, Fréderique Schortgen, Michel Dojat, Belen Cabello, Lila Bouadma, Pablo Rodriguez, Salvatore Maggiore, Marc Reynaert, Stefan Mersmann, and Laurent Brochard

Main Results: Weaning duration was reduced in the computer-driven group from a median of 5 to 3 d ($p = 0.01$) and total duration of mechanical ventilation from 12 to 7.5 d ($p = 0.003$). Reintubation rate did not differ (23 vs. 16%, $p = 0.40$). Computer-driven weaning also decreased median intensive care unit (ICU) stay duration from 15.5 to 12 d ($p = 0.02$) and caused no adverse events. The amount

AJRCCM 2006

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Other view…

Taniguchi *et al. Critical Care* (2015) 19:246
DOI 10.1186/s13054-015-0978-6

RESEARCH Open Access

Smart Care™ versus respiratory physiotherapy–driven manual weaning for critically ill adult patients: a randomized controlled trial

Corinne Taniguchi[1], Elivane S. Victor[1], Talita Pieri[1], Renata Henn[1], Carolina Santana[1], Erica Giovanetti[1], Cilene Saghabi[1], Karina Timenetsky[1], Raquel Caserta Eid[1], Eliezer Silva[1], Gustavo F. J. Matos[1], Guilherme P. P. Schettino[1] and Carmen S. V. Barbas[1,2*]

were significantly higher in the respiratory physiotherapy–driven weaning group. Total duration of mechanical ventilation (3.5 [2.0–7.3] days vs. 4.1 [2.7-7.1] days; p =0.467) and extubation failure (2 vs. 2; p =1.00) were similar between the two groups. Weaning duration was shorter in the respiratory physiotherapy–driven weaning group (60 [50–80] minutes vs. 110 [80–130] minutes; p <0.001).

Conclusion: A respiratory physiotherapy–driven weaning protocol can decrease weaning time compared with an automatic system, as it takes into account individual weaning difficulties.

SmartCare/PS

- A successful closed-loop PS weaning system.
- Works continually, without needing direct supervision

- Complex “expert system”
  - Tries to incorporate clinical information to adapt target.
  - Conservative algorithm

- May not be as quick as 24/7 bedside experts
  - Who can jump out of the algorithm.

More comprehensive approach

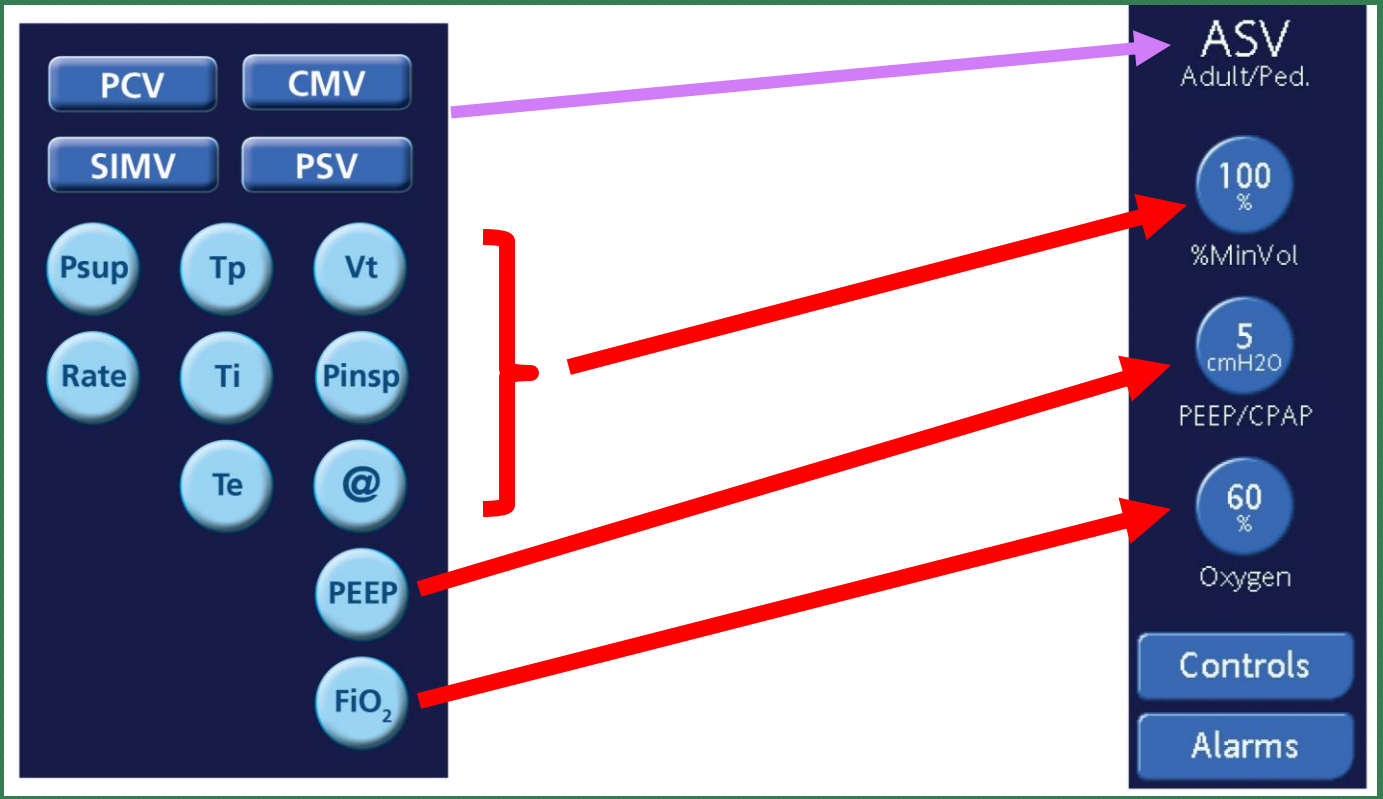
- Hamilton

  Adaptive Support Ventilation (ASV)

- Similar concepts incorporated in
  - imt AVM
  - Mindray AMV

- “Self-adjusting Pressure SIMV”

ASV : 3 fundamental settings



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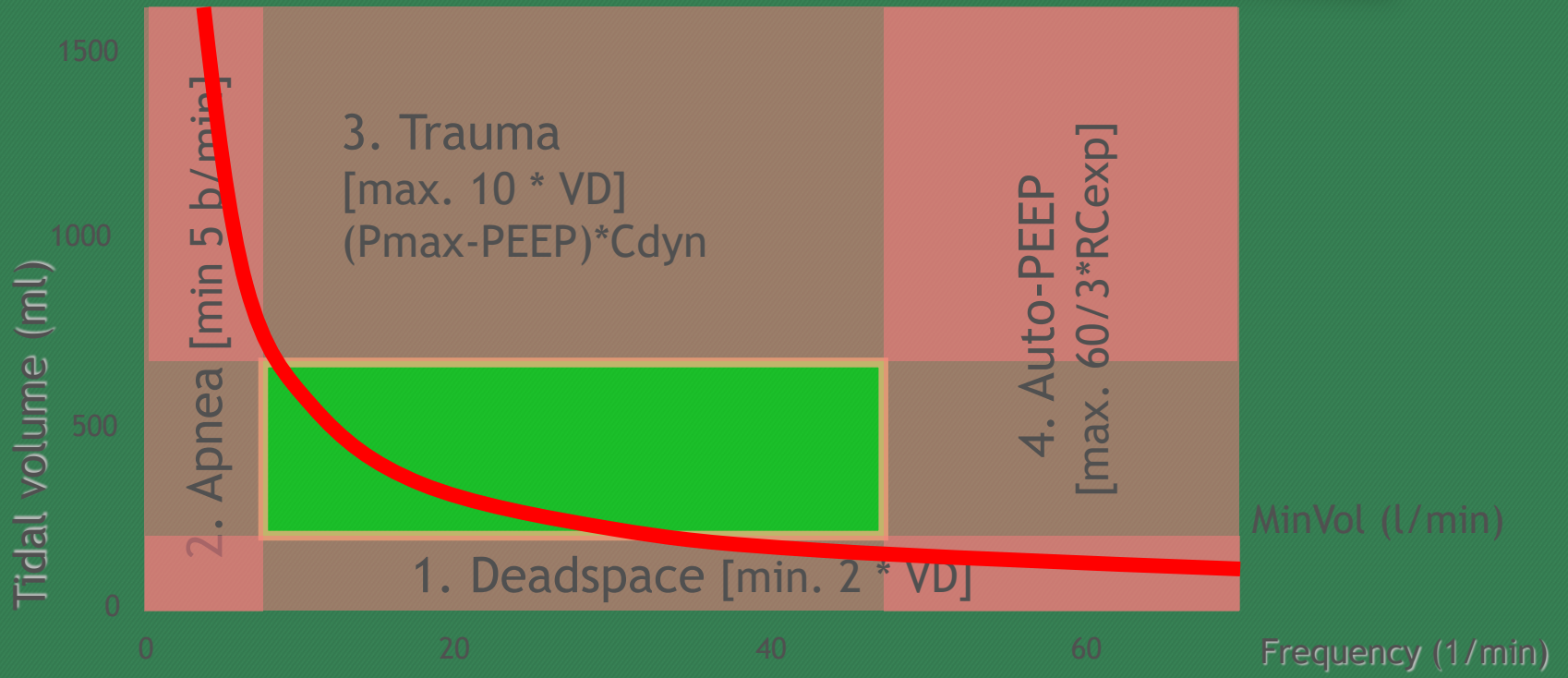
Loop closes Minute Volume

- Minute Volume = Breath Rate * (Alveolar) Tidal Volume

- ASV tries to achieve the set Minute Volume using a combination of :
  - Tidal Volume
    - not too big (volutrauma) causes excess pressure (barotrauma)
    - not too small (gas trapping, auto-PEEP)

  AND
  - Breath Rate
    - not too slow (would need too big a Tidal Volume)
    - not too fast (too little time for exhalation … gas trapping … auto PEEP)

Minute Volume combination line … and safety limits



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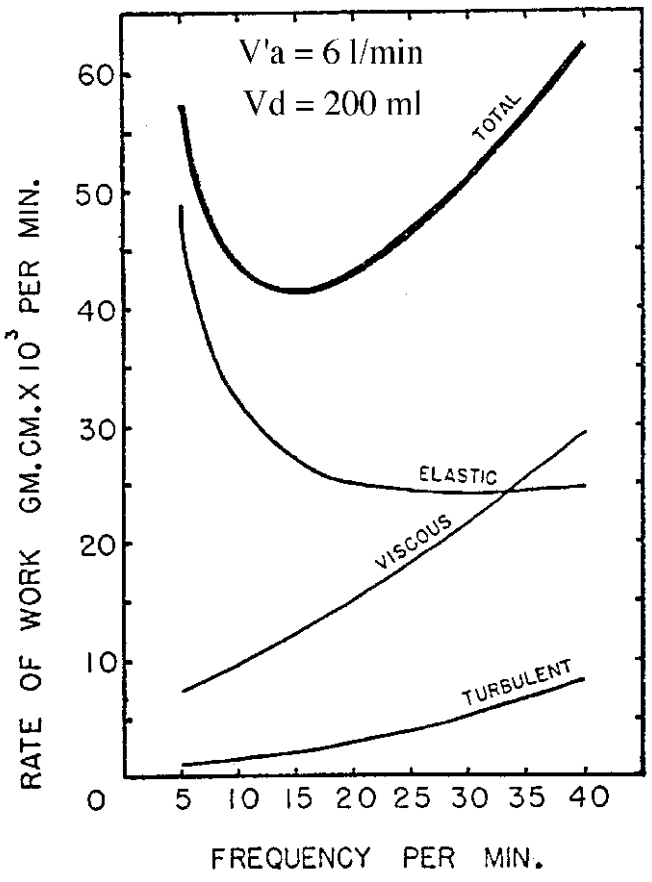
ASV 1.0 : “Otis Equation” … minimal Work of Breathing



For any combination of Resistance, Compliance, V’a and Vd, there is a Respiratory Rate where WOB is minimal

$$f\text{-target} = \frac{\sqrt{1+2a*RCexp*(MV-V'D)/VD} - 1}{a*RCexp}$$

- Otis AB, Fenn WO, Rahn H
- Mechanics of breathing in man
- JAP 1950; 2: 592-607

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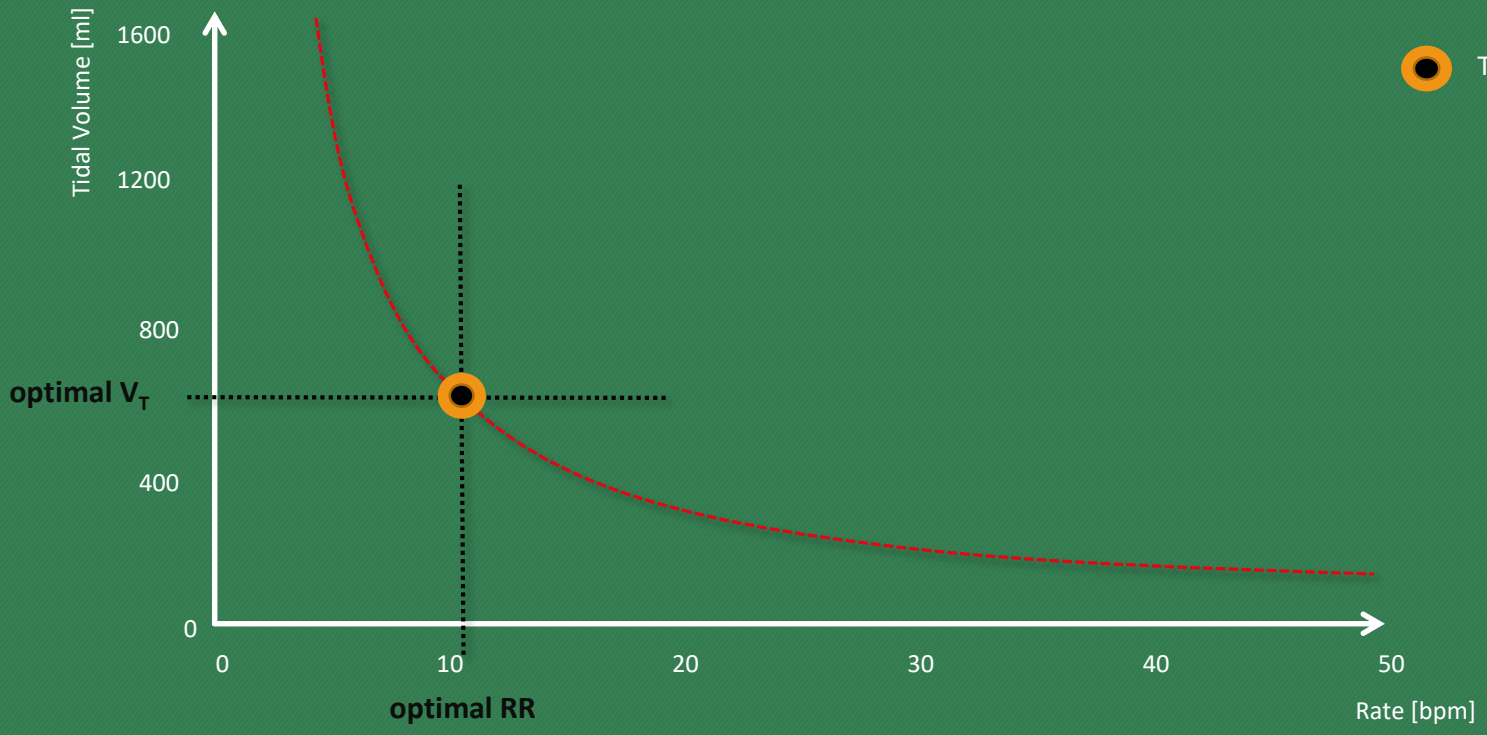
“The ideal point”



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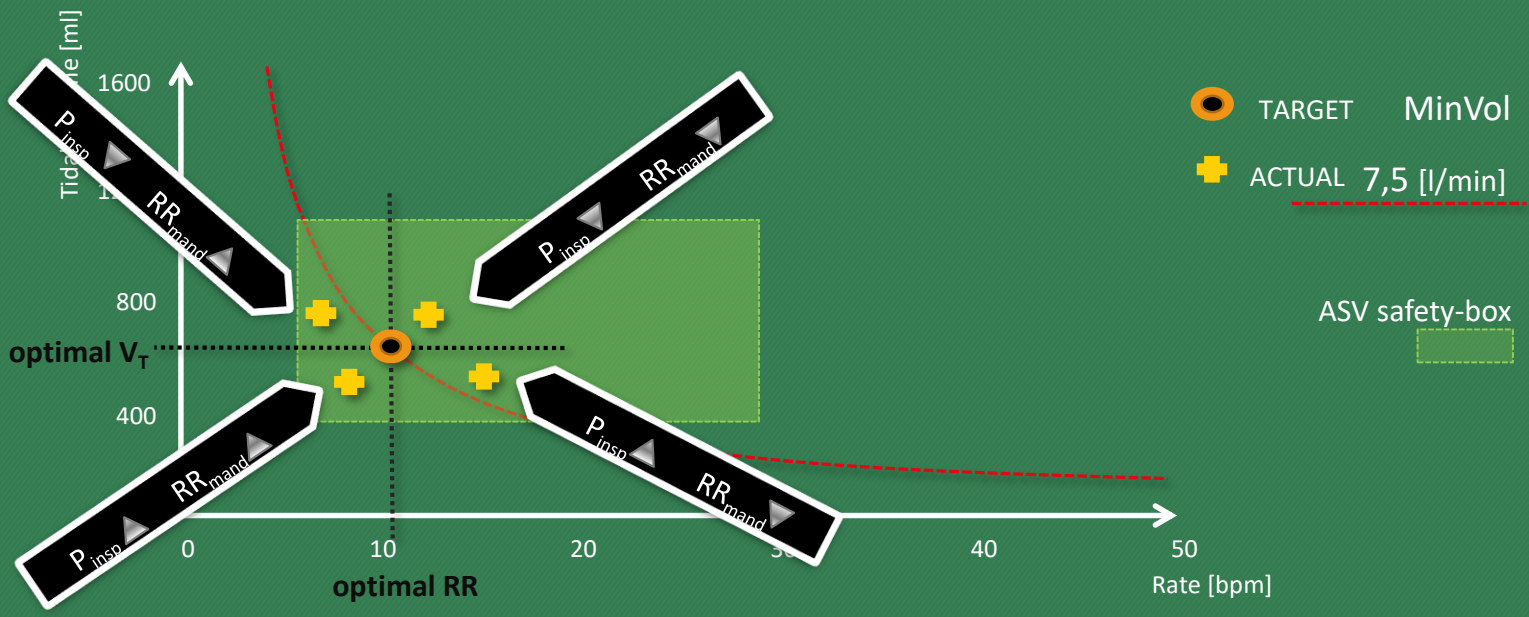
Adjusting breaths



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2017-02-17
14:04:12
INTELLiVENT
ASV
Adult
Patient
Additions
Modes
Trend
IntelliCuff
40
5
16 Ppeak cmH2O
10.0
4.0
6.1 ExpMinVol l/min
184 VTE ml
23
18 fTotal b/min
1:1.5 I:E
Paw cmH2O
20
15
10
5
0
s
1 2 3 4 5 6 7 8 9 10
Flow l/min
50
25
0
-25
-50
195 VTI ml
184 VTE ml
--- VTESpont ml
6.1 ExpMinVol l/min
0.00 MVSpont l/min
4 / 9
V ml
Target
Current
800
600
400
200
0
MinVol
5.6
l/min
f
b/min.
0 10 20 30 40 50 60
fSpont
0
b/min
fControl
18
b/min
Pinsp
8
cmH2O
Oxygenation
CO2 elimination
Spont/Activity
40 21
10 0
8.4 2.8
10 0
100 10
75 100
00:09
00:08
00:00
Oxygen
50
%
PEEP
8
cmH2O
MinVol
6.1
l/min
Pinsp
7
cmH2O
RSB

1/(f*min)
%fSpont
0
%
100
%
%MinVol
8
cmH2O
PEEP/CPAP
50
%
Oxygen
Controls
Alarms
Monitoring
Graphics
Tools
Events
System
INT
AC

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Note:

- ASV 1.0 algorithm tended to give large VT
- ASV 1.1 uses 2nd equation
  - Mead equation : least force of breathing
  - Averages Otis & Mead
- Gives VT closer to 6ml/kg PMFH

Auto-adjusting SIMV

- Starts with “mandatory breaths”
  - Scales driving pressure to get correct VT
- Incorporates spontaneous breaths
  - Reduces mandatory breath number if enough spontaneous : ultimately to zero
  - Effectively changes to PSV
- In spontaneous breaths : reduces driving pressure
  - Automatically reduces PSV pressure

- *So machine-controlled SIMV is a weaning mode!*

Pros and cons

- Pro: can flexibly revert back and forth to mandatory breaths if patient drive inadequate
- Con: once patient stable in PSV it can over-respond to blips
  - Still needs a human check
- Effective loop closure on maintaining set minute volume
  - Clinician must determine what that MV should be
  - According to clinical CO_2 goals
- No loop closure on oxygenation

Add some more toys

- MV targeting mainly affects CO_2
- Add volumetric capnograph
  - Machine can now adjust MV target to reach clinician-set CO_2 target
  - Modified by whether ARDS / COPD / rICP present
- Add pulse oximeter
  - Machine can adjust PEEP and FiO_2 to achieve clinician-set SpO_2
- Clinician can set constraints

Intellivent

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Intellivent

- Requires four screens of setup
  - Base pathology
    - Affects CO_2 target hence MV
  - Constraints on PEEP and FiO_2
  - Aggressive wean requested
  - Alarm limits
- Has proven effective in rapidly AND CONSISTENTLY weaning patients.

Final thoughts

A useful option

- Medical technology lags 10 years behind your cellular phone.
  - FDA checks take years
- Great improvements in AI are coming.
- No algorithm yet perfect
  - Partly because knowledge is deficient
- But tasks requiring CONSISTENCY may be better done by machines.
- Weaning requires insight and consistency.

Thank you.

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