Design and maintenance of mechanical ventilator: Conventional and Novel modes

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Outline

- Lectures from History
- Basic structure and main functional components
- Physics of Mechanical Ventilators
- Phase of Mechanical Breath
- Convention mode
- Novel mode
- Artificial Intelligence for Mechanical Ventilation

Lectures from History

Claudius Galenus 克勞迪亞斯·蓋倫, Greek physician and scientist
體液學說：血液、黏液、黃膽汁和黑膽汁

‘‘You can clearly see this for yourself, even after the animal is dead, if you blow air through the rough artery into the whole lung and then empty it out again by pressure’’ .

‘‘If, when the animal is already dead you blow air in through the larynx, you will, of course, fill the rough arteries and you will see the lung expanded to its greatest extent while the smooth arteries and the veins in the lung maintain their size unchanged’’

Resuscitation. 2001 May;49(2):119-22. Galen and the origins of artificial ventilation, the arteries and the pulse

Lectures from History

Galen, Greek physician and scientist

1864, Alfred Jones

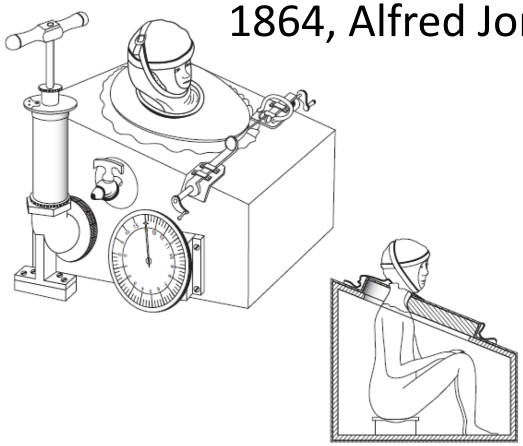


Figure 2. Body-enclosing box. One of the first known body-enclosing boxes; patented by Alfred Jones in 1864. Reprinted from Reference 12.

1908, Peter Lord

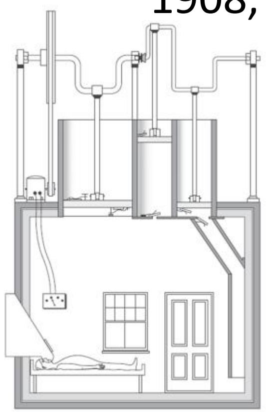
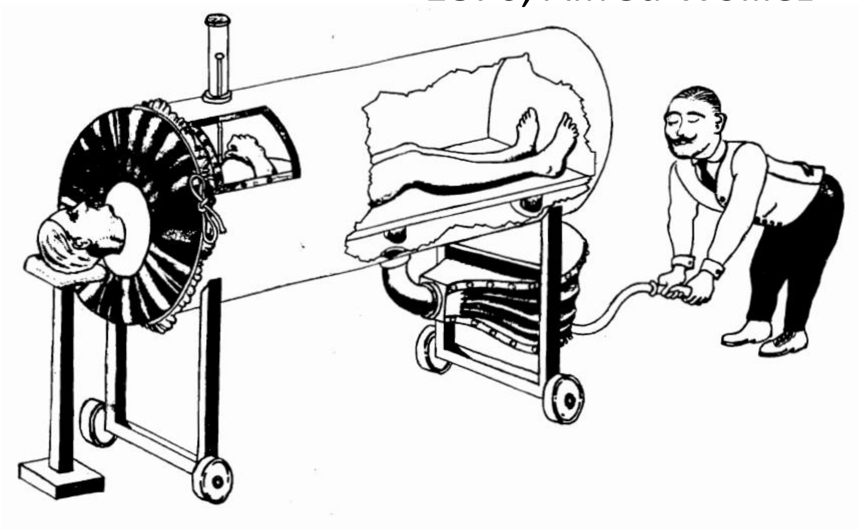


Figure 3. Respirator room. Pressure changes in the room were generated by huge pistons, which created pressure changes in the thoracic cavity, which in turn caused gas to move into and out of the patient who was connected via a manifold to a fresh gas supply outside the room. Adapted from Reference 50.

The Breath of Life
The Prophet Elisha Reviving the Shunammite Child—II Kings 4:34 35
(Redrawn from painting by Lord Frederick Leighton)

1876, Alfred Woillez



1926, Wilhelm Schwake

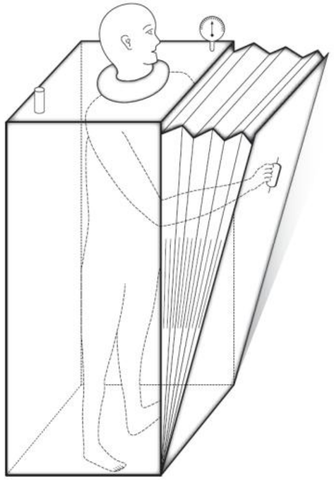


Figure 4. Pneumatic chamber: Patented by Wilhelm Schwake in Germany in 1926 (51). Schwake was concerned with precise matching of the ventilator and the patient's breathing pattern. Reprinted from Reference 13.

Resuscitation. 2001 May;49(2):119-22. Galen and the origins of artificial ventilation, the arteries and the pulse

The Evolution of Iron Lungs, 1958

Lectures from History

1911, Dräger’s Pulmotor

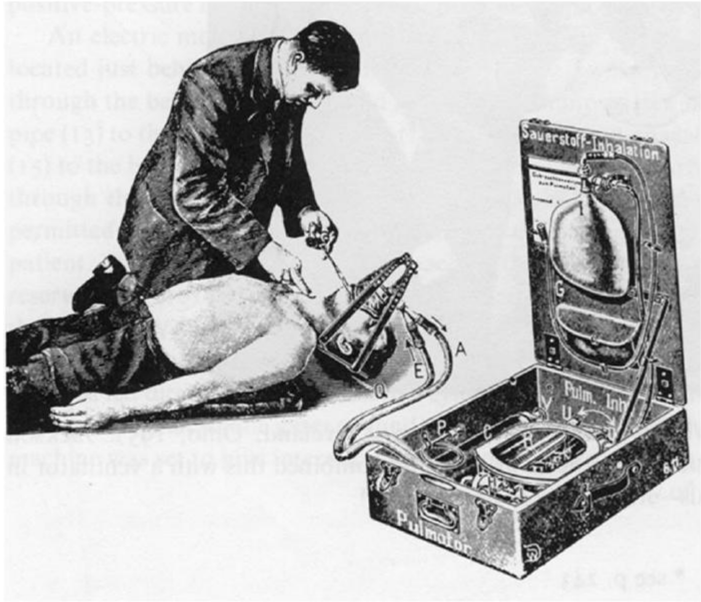


Fig. 3. Poliomyelitis epidemic patients at Ranchos Los Amigos Hospital, California, 1953. (From Reference 8.)

1950s, Poliomyelitis epidemic

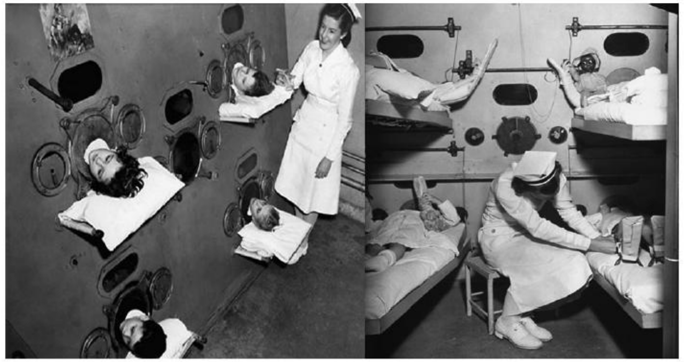
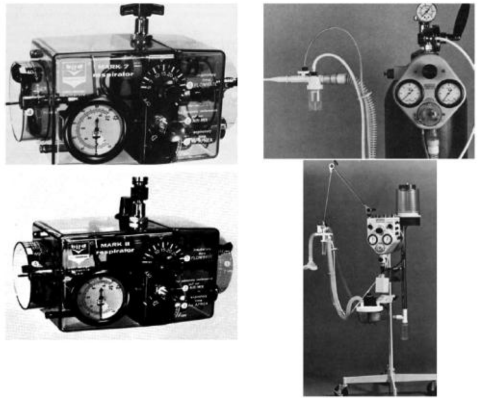


Fig. 4. Multi-person negative-pressure ventilator at Boston Children’s Hospital, 1950s. (From Children’s Hospital Boston Archives, with permission.)



1960s, Bird Mark 7/8, NIV (volume/C)
Bennett TV-2P & PR-2

Lectures from History

Table 1. Generations of Intensive Care Ventilators

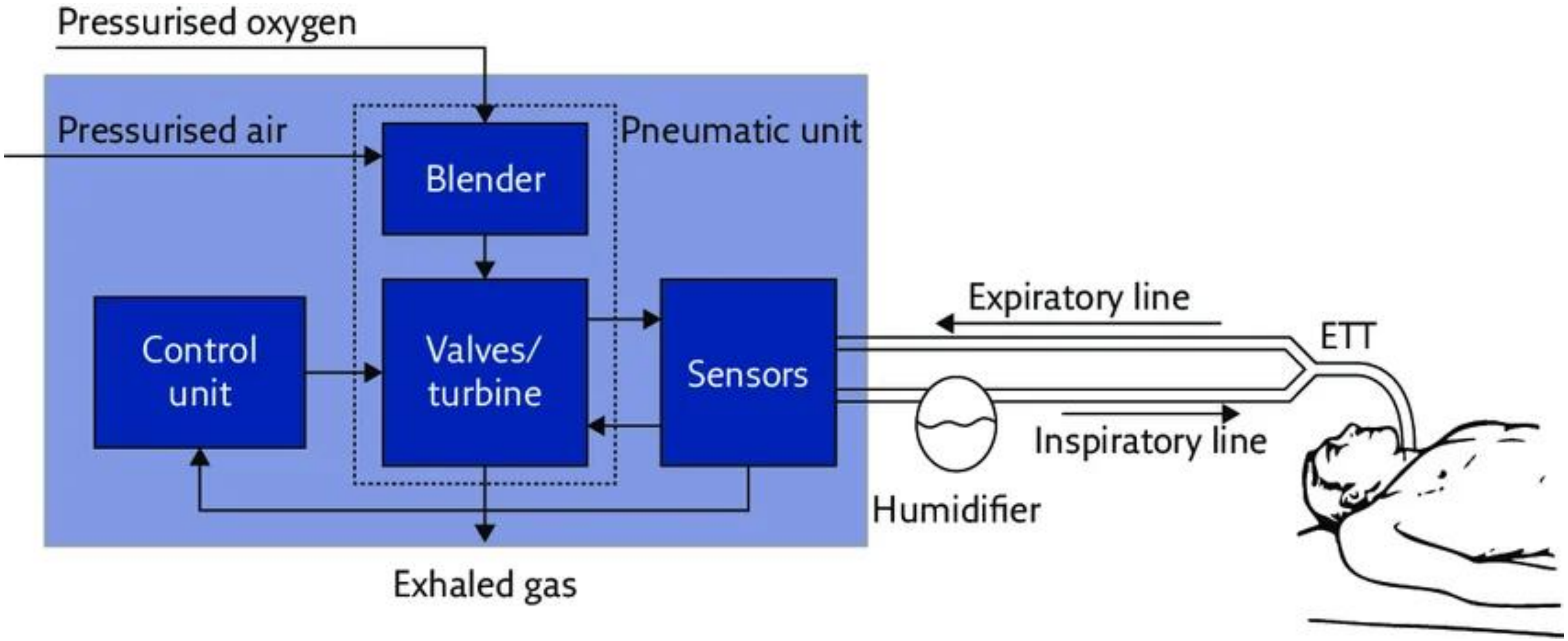
Generation	Years	Distinguishing Features
First	Early 1900s to mid-1970s	Only volume-controlled ventilation
Second	Mid-1970s thru early 1980s	First appearance of patient-triggered inspiration
Third	Early 1980s through late 1990s	Microprocessor control
Fourth	Late 1990s to present	Plethora of ventilation modes
Future	Only time will tell	Smart ventilation providing decision support

- No monitors, no alarms
- I/E ratio fix 1:2
- No PEEP

- Still only Volume-controlled
- Include Basic alarms
- Closed-loop ventilation

Robert M Kacmarek. The Mechanical Ventilator: Past, Present, and Future

Basic structure and main functional components



Breathe (Sheff). 2017;13(2):84-98. Trends in mechanical ventilation: are we ventilating our patients in the best possible way?

Physics of Mechanical Ventilators

- Input power
- Drive mechanism
- Source of Gas supply
- Control circuit

Input power

- Pneumatic: compressed gas from wall outlets

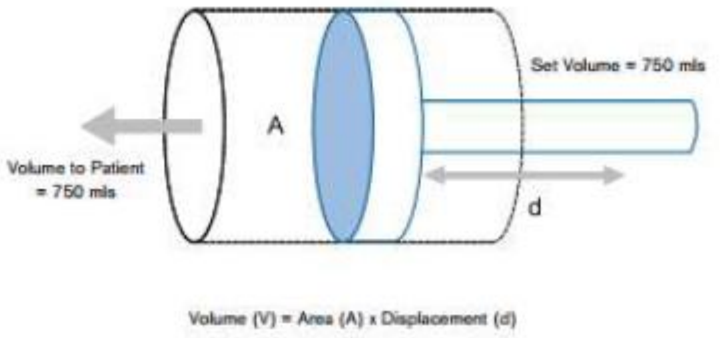
Usually supplied via external power source as well as via hospital’s central gas supply (approximately 50 psi)

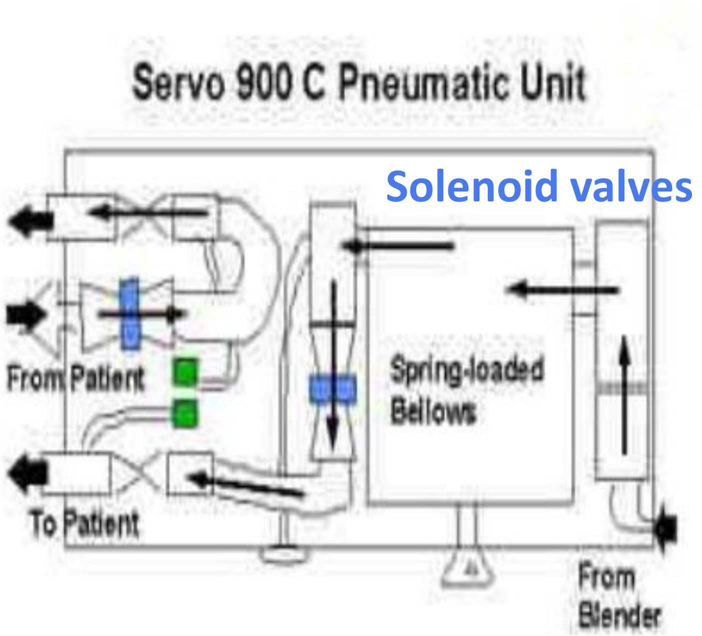
- Electric

AC or DC (battery)current is used to drive the pistons and compressors that generate pressure.

Drive Mechanism

- Power Transmission System which responsible for breath delivery to the patient
- 3 types: pistons, bellows, and pneumatic circuits.





Source of Gas supply

Both oxygen and air are required

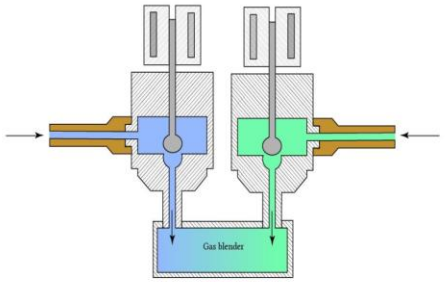
- Air

Central compressed air, compressor, turbine flow generator

- Oxygen

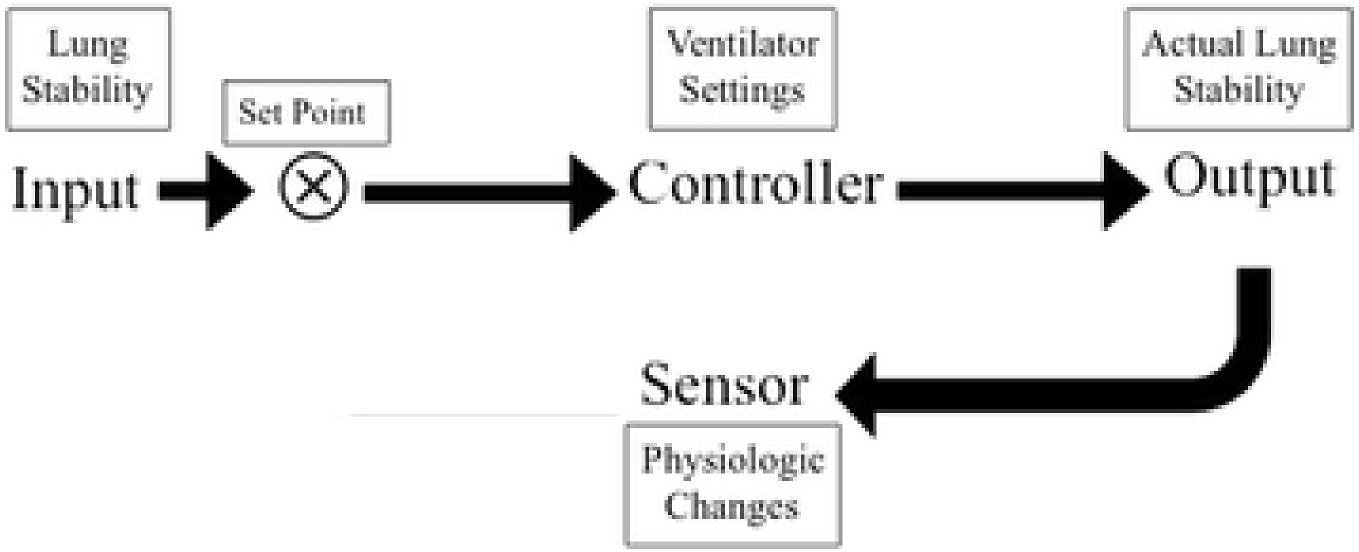
Central oxygen source, O2 concentrator, O2 cylinder

- Gas mixing unit – O2 blender

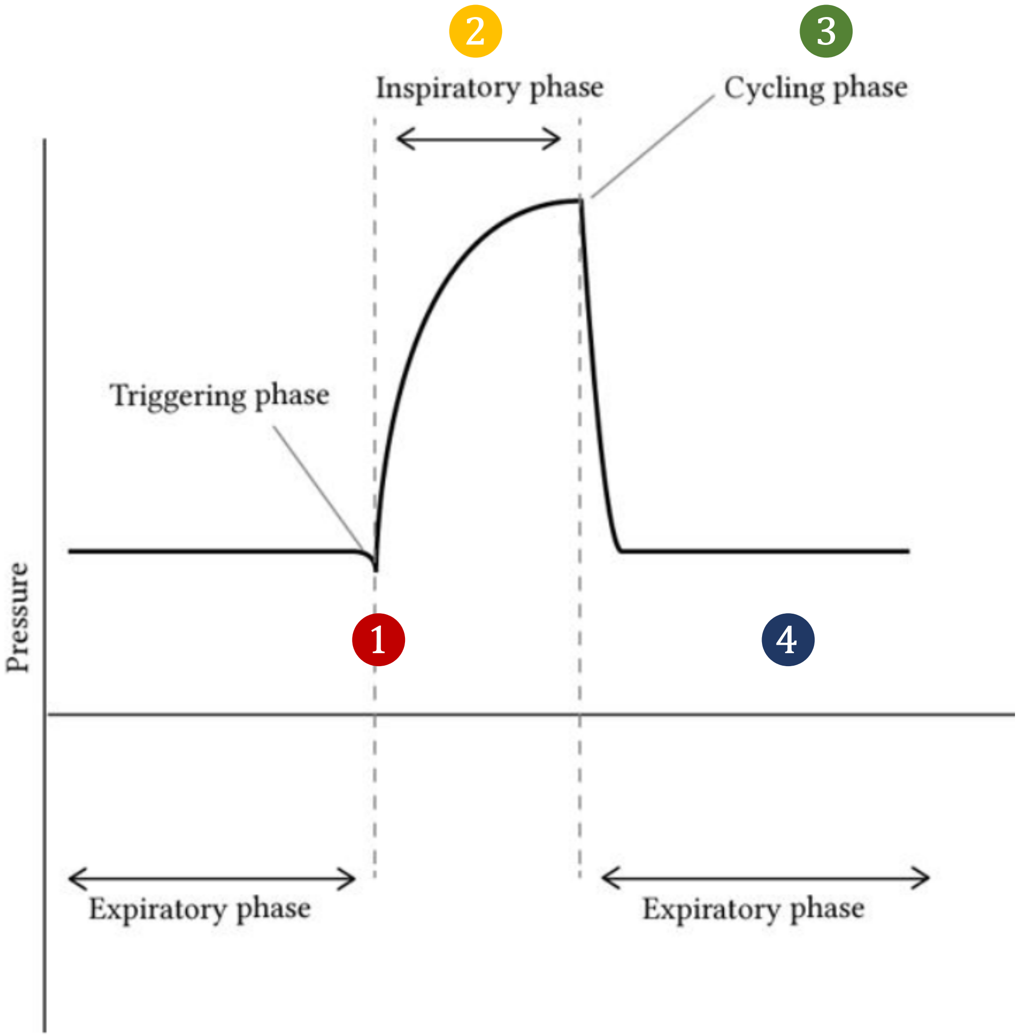


Control circuit

Open -Loop Feedback System



Phases of Mechanical Breath



1 Initiation phase: **Trigger variable**
Mandatory/ Spontaneous
Time, Flow and Pressure

2 Inspiratory phase: **Limit variable** (Target)
Pressure, Flow or Volume

3 Cycling phase: **Cycle variable**
Time cycling, Flow cycling and Pressure cycling

4 Expiratory phase: **PEEP variable**

Common Ventilator Modes

Full support Mode

CMV

Continuous (control) Mandatory Ventilation

Partial support Mode

IMV

Intermittent Mandatory Ventilation

Spontaneous Breathing

CSV

Continuous Spontaneous Ventilation

VCV

PCV

SIMV

PSV

CPAP

ATC

Common Ventilator Modes

Full support Mode

CMV

Continuous (control) Mandatory Ventilation

- VCV
- PCV

Partial support Mode

IMV

Intermittent Mandatory Ventilation

- SIMV

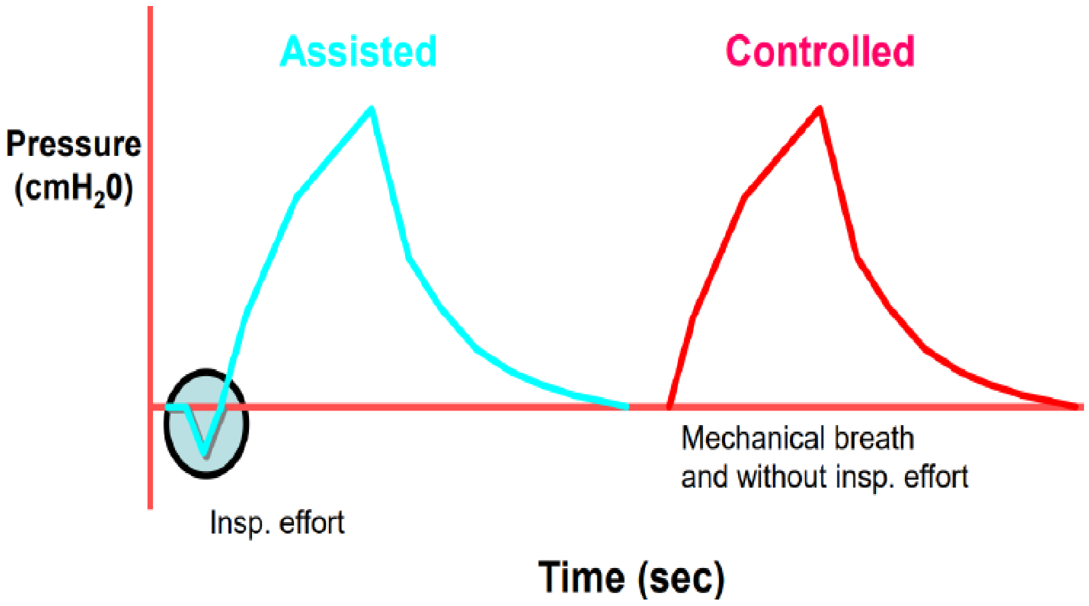
Spontaneous Breathing

CSV

Continuous Spontaneous Ventilation

- PSV
- CPAP
- ATC

Common Ventilator Modes



- Mandatory/ Spontaneous
  - Time(Set Rate), Flow and Pressure

- Assist/Control mode
  - 無引動 (sedation, trigger 不足)→ Control
  - 可引動 → Assist mode

VCV (Volume control ventilation)

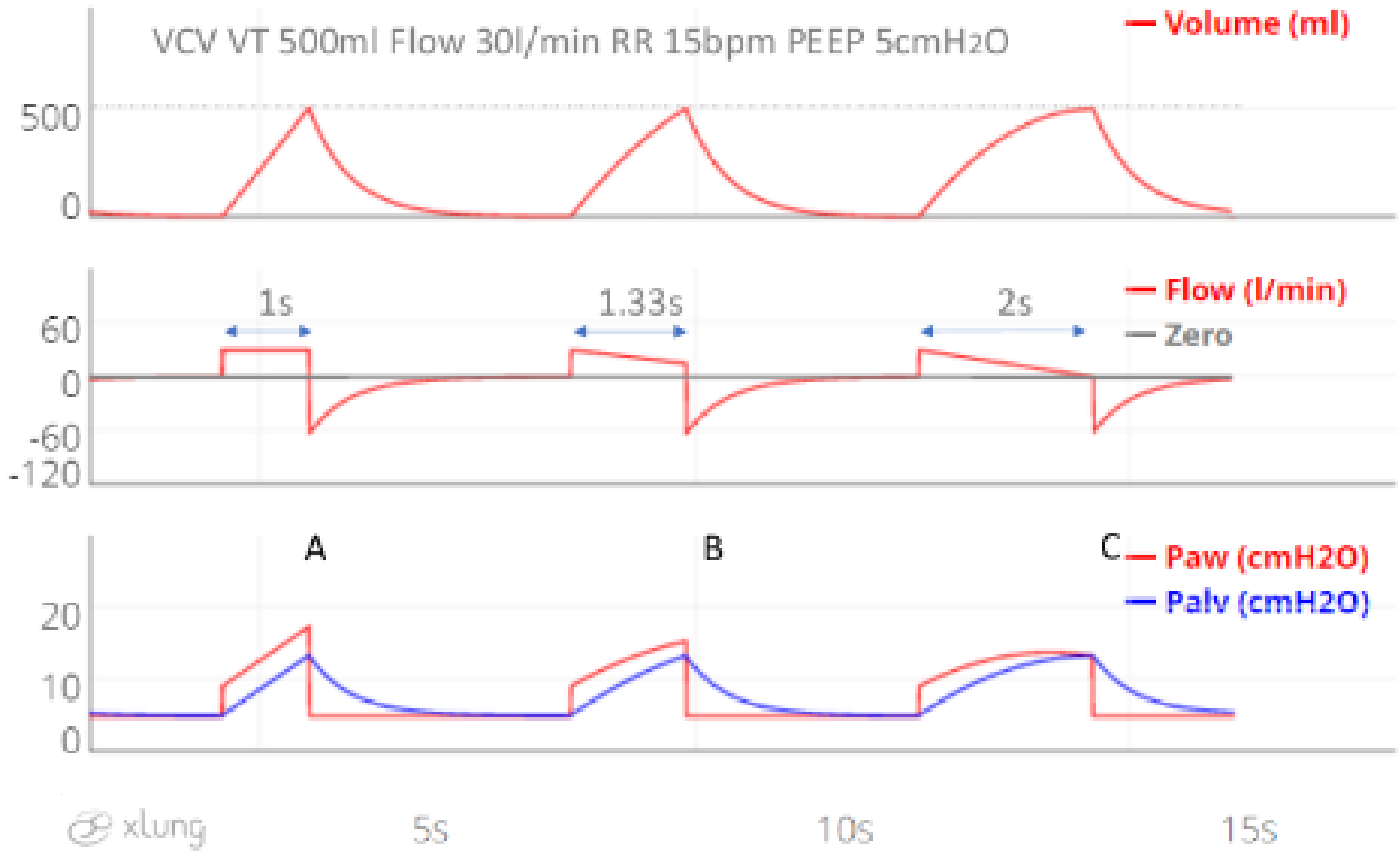
- Settings
  - Trigger: P't or Time
  - Target: Volume
  - Limit: Inspiratory flow
  - Rate
- Vt = flow x Ti
- Advantages

Assured minute Ventilation

- Disadvantages

Unmet need for high breathing demand

Risk for Barotrauma



PCV (Pressure control ventilation)

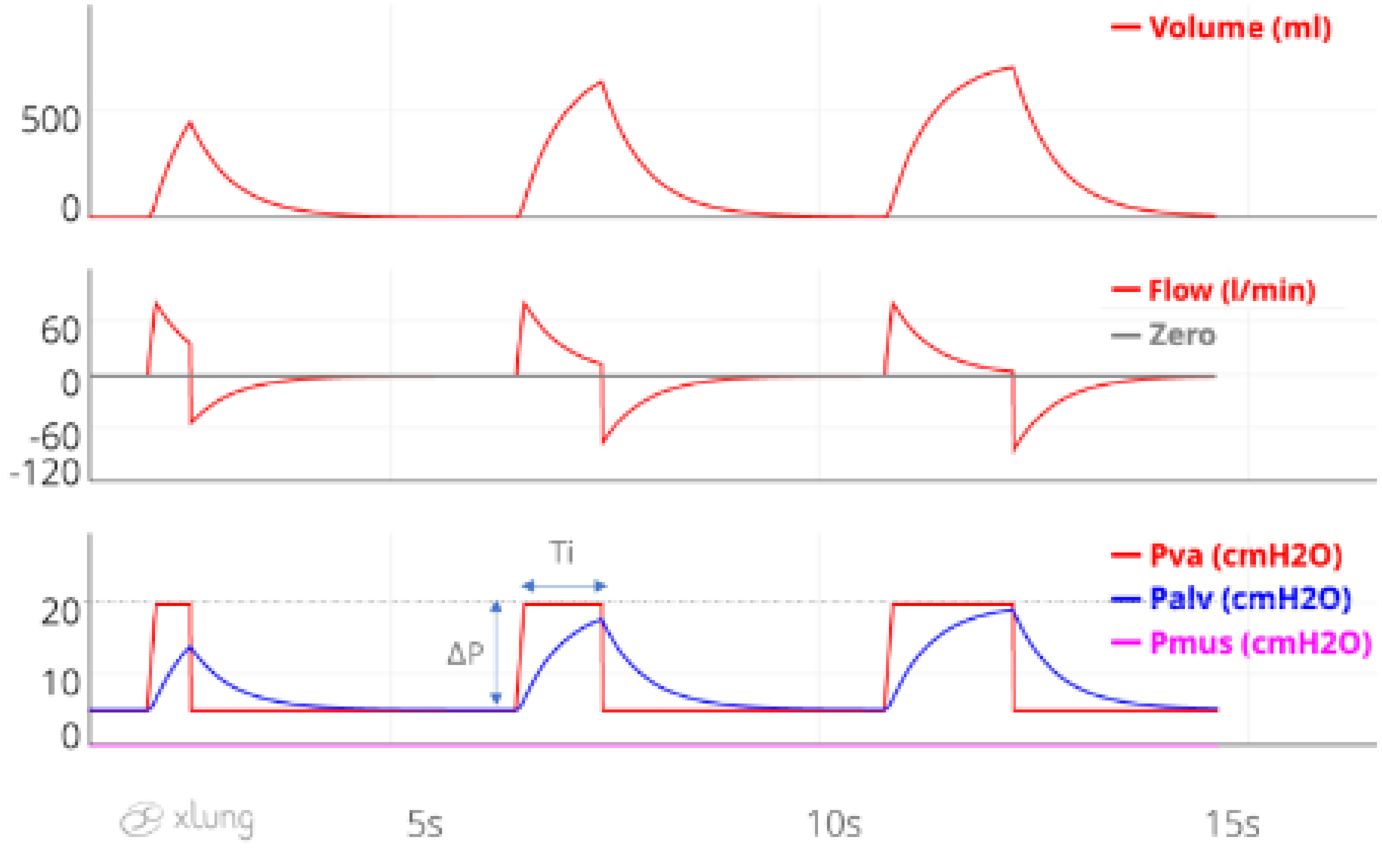
- Settings
  - Trigger: P't or Time
  - Target: Pressure
  - Rate
  - Ti , time of inspiration
- Advantages

Lower risk for barotrauma

Better for high breathing demand

- Disadvantages

Unstable volume



Common Ventilator Modes

Full support Mode
CMV
Continuous (control) Mandatory Ventilation

VCV
PCV
PRVC
VAPS

Partial support Mode
IMV
Intermittent Mandatory Ventilation

SIMV

Spontaneous Breathing
CSV
Continuous Spontaneous Ventilation

PSV
CPAP
ATC

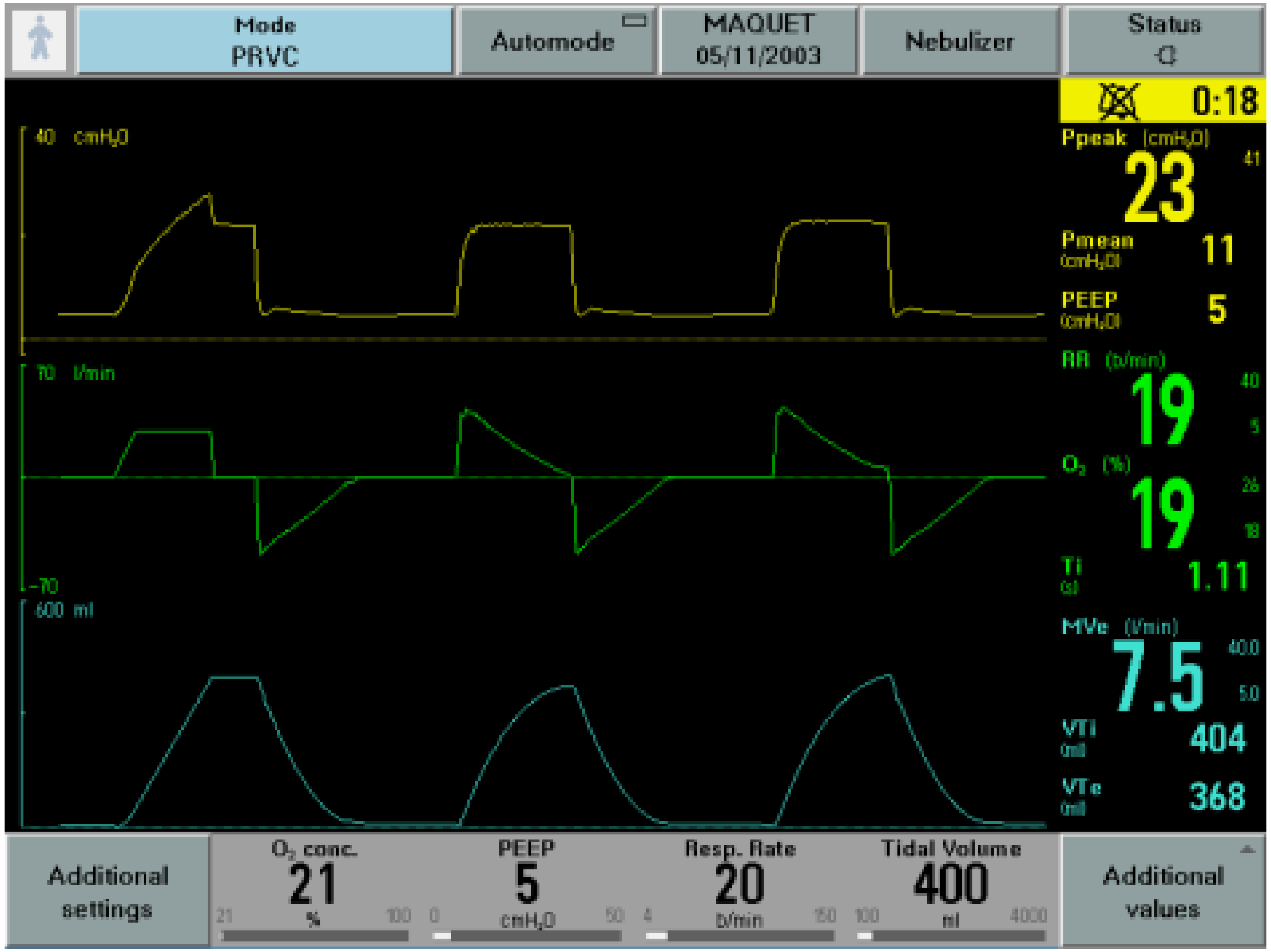
PRVC (Pressure regulated volume control)

- Settings
  - Trigger: P't or Time
  - Target: Volume
  - Rate
  - Ti, time of inspiration
- 1st VCV, then PCV *(previous Pplt)* , monitor Tv
- Advantages

Lower risk for barotrauma

Assured minute Ventilation

- Disadvantages



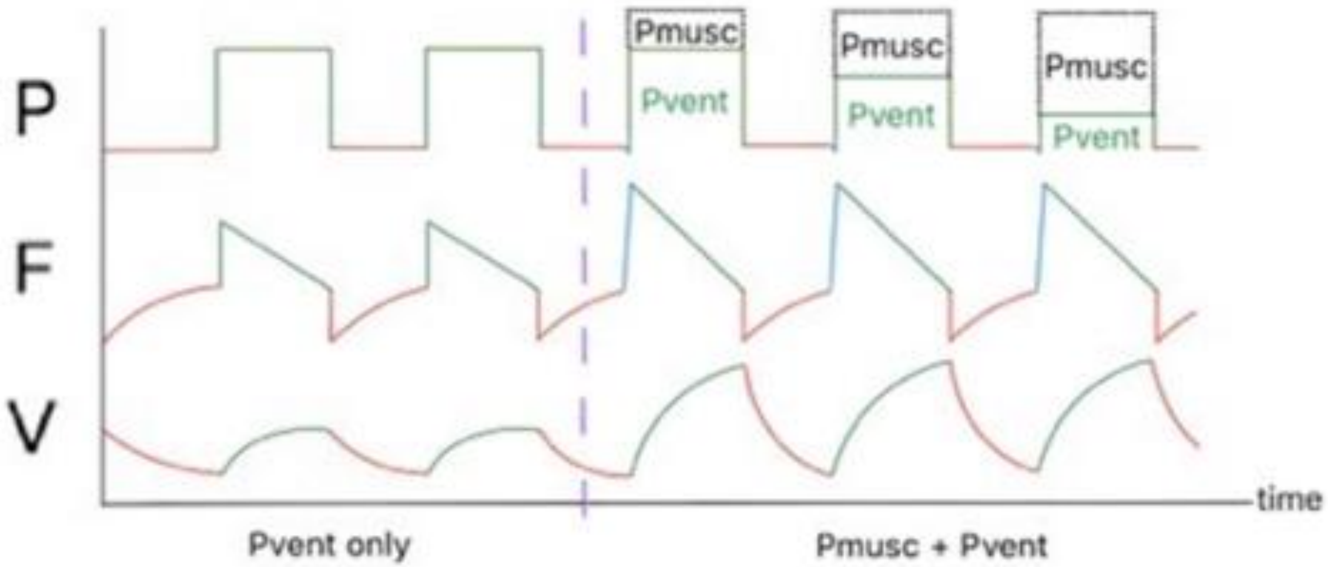
PRVC (Pressure regulated volume control)

- Settings
  - Trigger: P’t or Time
  - Target: Volume
  - Rate
  - Ti , time of inspiration
- 1st VCV, then PCV *(previous Pplt)* , monitor Tv
- Advantages

Lower risk for barotrauma

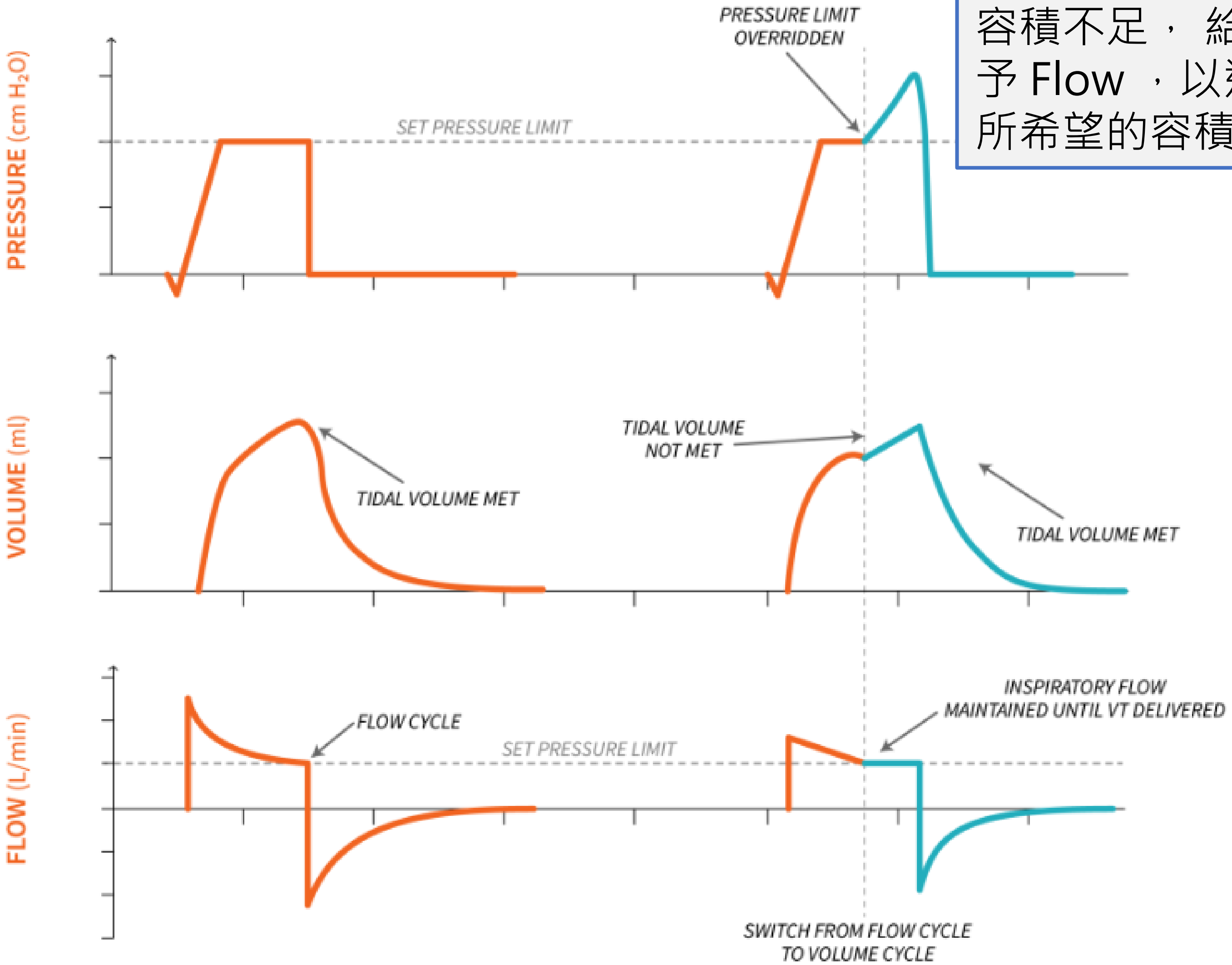
Assured minute Ventilation

- Disadvantages



VAPS (Volume assured Pressure support)

- Settings
  - Target: Volume
  - Range of values for the IPAP
  - EPAP
- 1st Loop,
  - IPAP min
  - VT/60 ml/cmH2O + EPAP
  - 8 cm/H2O + EPAP cmH2O



容積不足， 給予 Flow ，以達所希望的容積

Common Ventilator Modes

Full support Mode
CMV
Continuous (control) Mandatory Ventilation

Partial support Mode
IMV
Intermittent Mandatory Ventilation

Spontaneous Breathing
CSV
Continuous Spontaneous Ventilation

VCV

PCV

SIMV

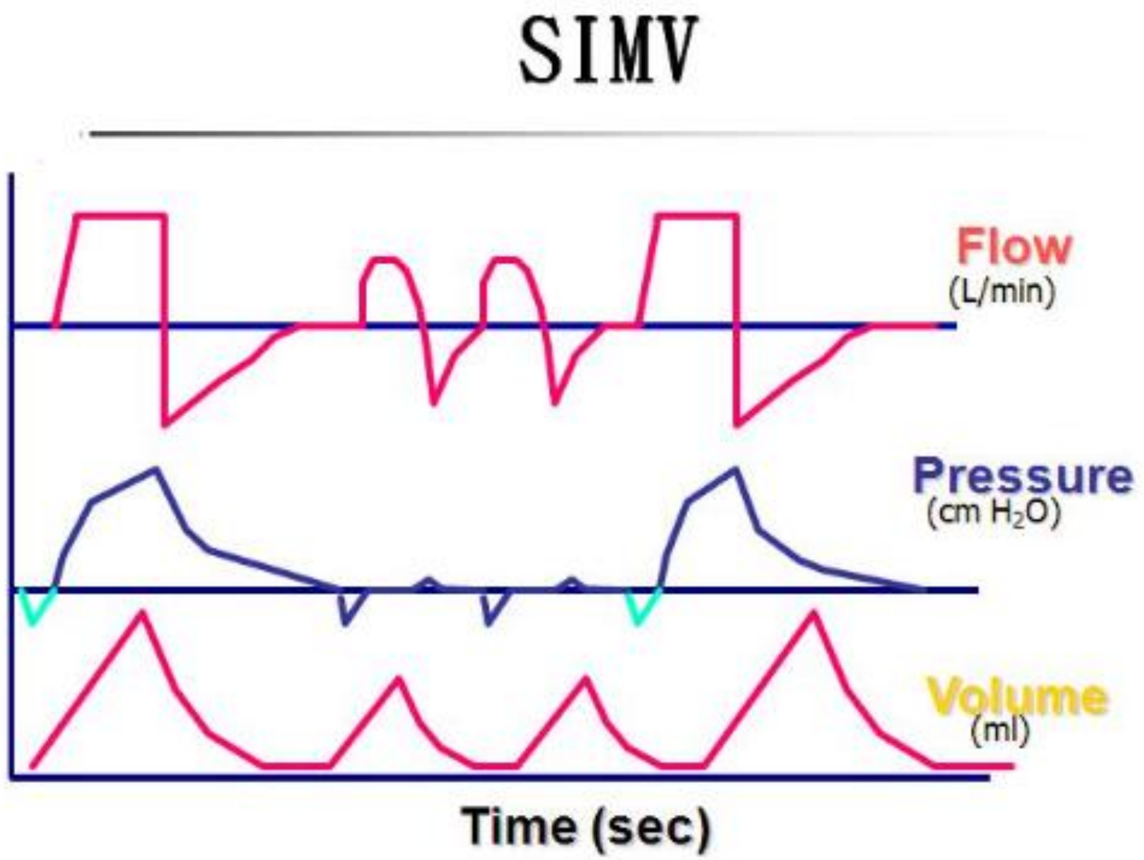
(完全支持通氣 VCV, PCV, PRVC) +
(部分支持通氣 PSV, VS)

PSV

CPAP

ATC

Intermittent Mandatory Ventilation



(完全支持通氣 VCV, PCV, PRVC) +
(部分支持通氣 PSV, VS)

Common Ventilator Modes

Full support Mode
CMV
Continuous (control) Mandatory Ventilation

Partial support Mode
IMV
Intermittent Mandatory Ventilation

Spontaneous Breathing
CSV
Continuous Spontaneous Ventilation

VCV

PCV

SIMV

PSV

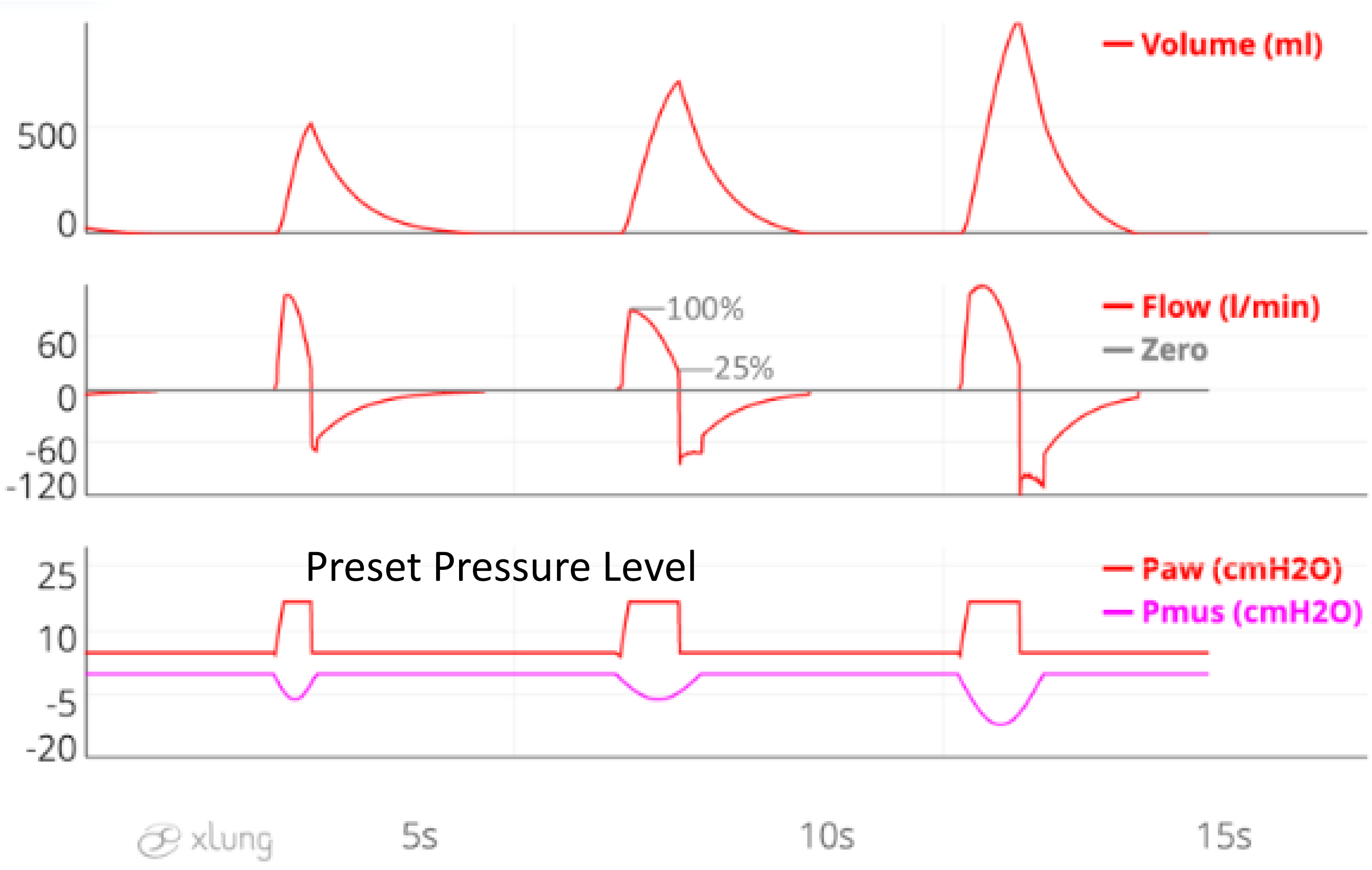
CPAP

ATC

VS

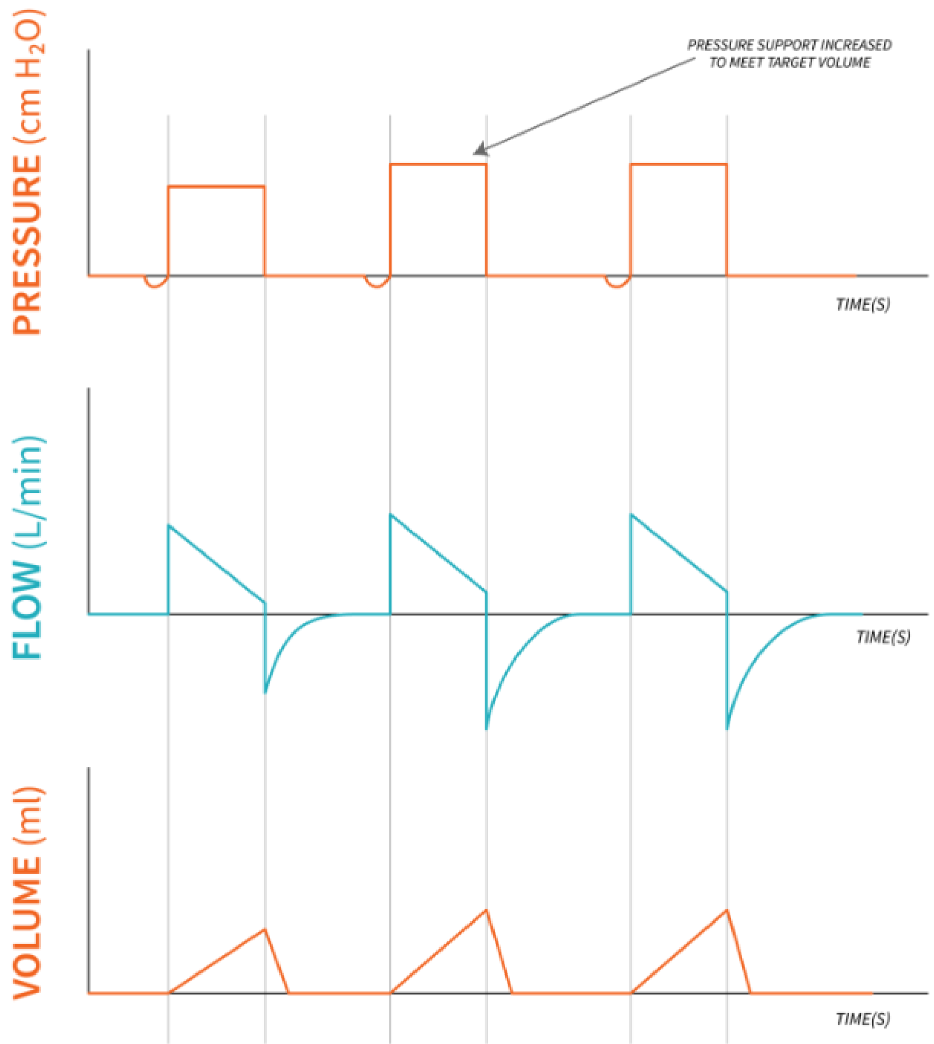
PSV (Pressure support ventilation)

- Settings
  - Trigger: Patient
  - Target: Pressure
  - Cycle: (%) Peak Insp Flow
  - Flow, VT, and Ti can vary



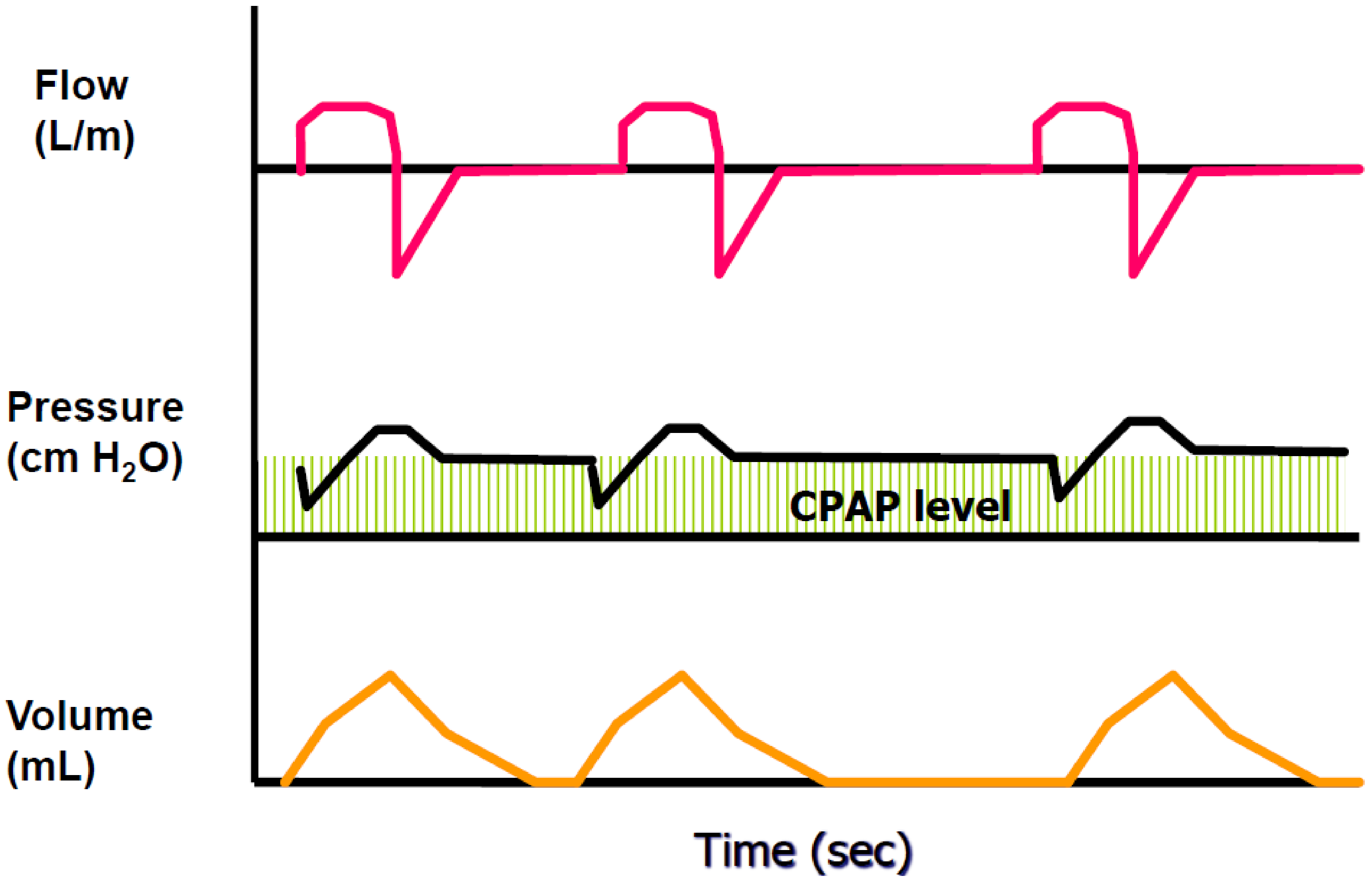
VS (Volume support)

- Settings:
  - Trigger: Patient
  - Target: Volume
  - Cycle: (%) Peak Insp Flow



CPAP (Continuous positive airway pressure)

- Settings: 吐氣末陽壓



ATC (Automatic tube compensation)

- Settings:
  - IBW
  - Tube type (ETT/Trach.)
  - Tube ID
  - % of support
- Not a mode, but a spontaneous breath type
- Overcome inspiratory WOB through an artificial airway

Mandatory Minute Ventilation (MMV)

- 最低每分鐘通氣量 = VT × RR

Mandatory
- Target: Volume
- Limit: Inspiratory flow
- Rate

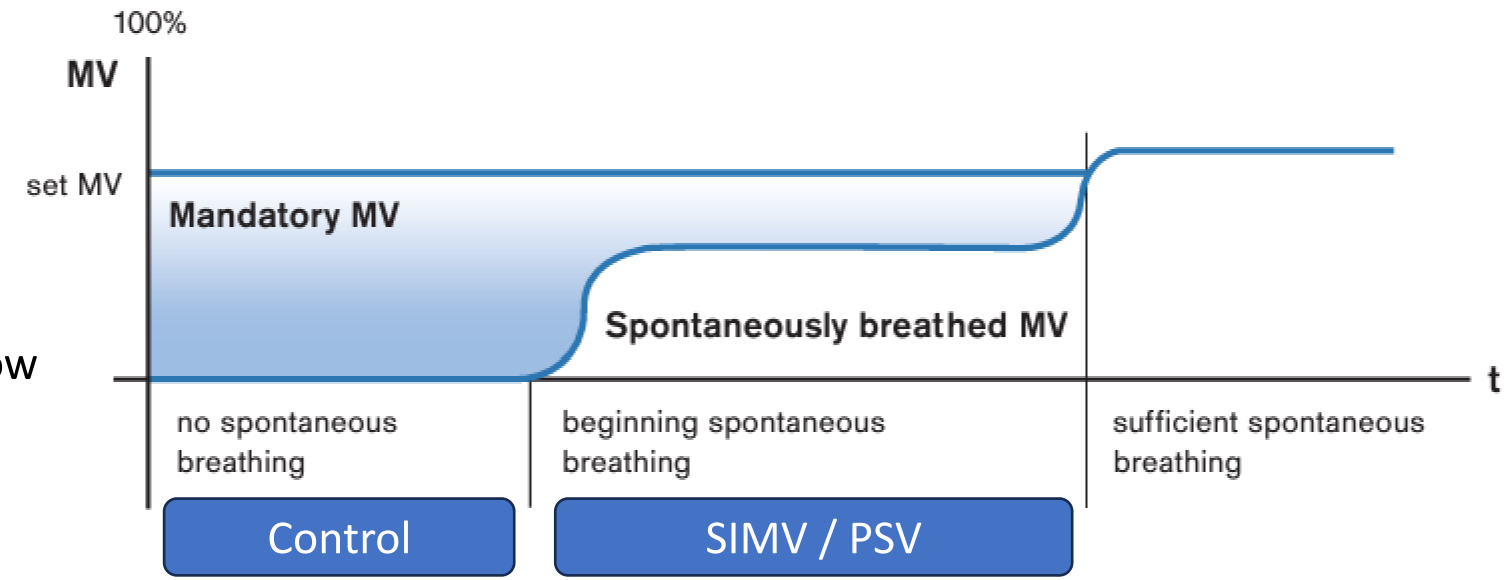


Figure 3. Seamless apnoea ventilation and weaning during PC-MMV
The infant is transferred seamlessly from 100 % mandatory ventilation to 100 % spontaneous breathing during PC-MMV without clinician intervention to reduce mandatory rate.

Disadvantages:

呼吸器沒辦法知道病患確切呼吸情形，若病患透過增加呼吸次數達到每分通氣量，仍被視為正常

Adaptive Support ventilation (ASV)

依據病患肺部生理Ve,Vd,RCe 算出最低呼吸作功時的 Vt 和 rate, 病患不論於自發性或機械式呼吸時皆可建立最適當呼吸型態及最小呼吸功

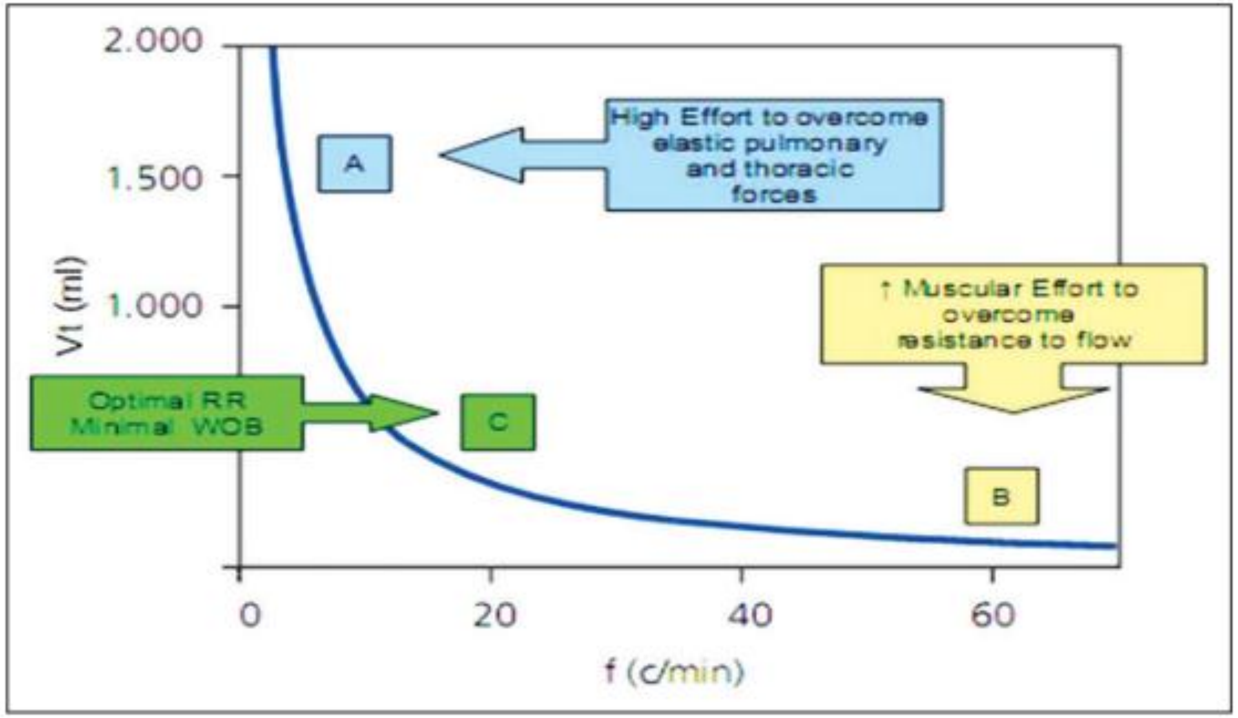


Figure 2: Tidal volume against respiration rate

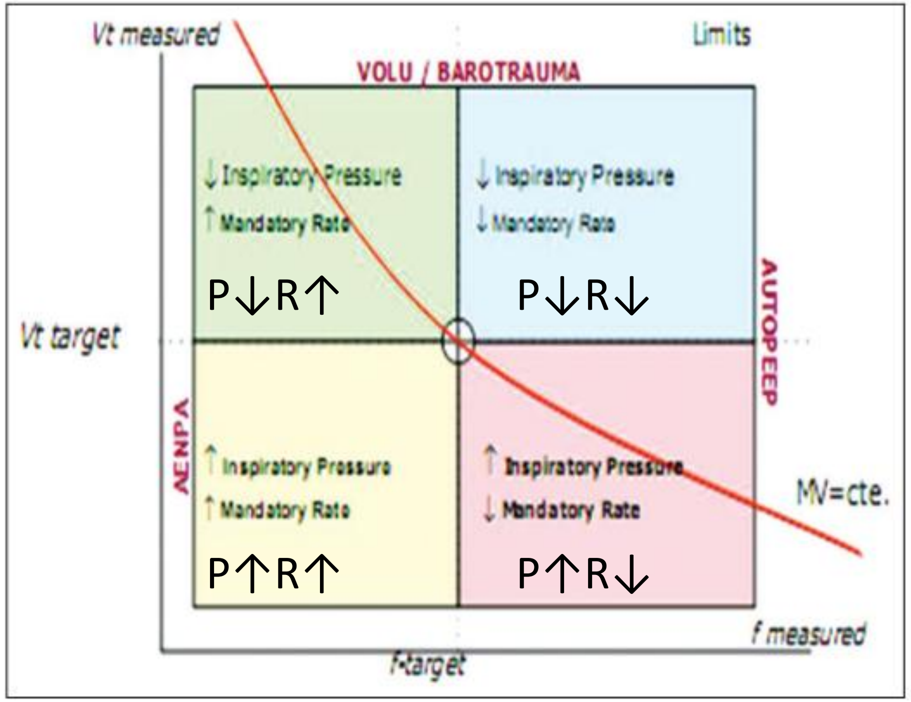
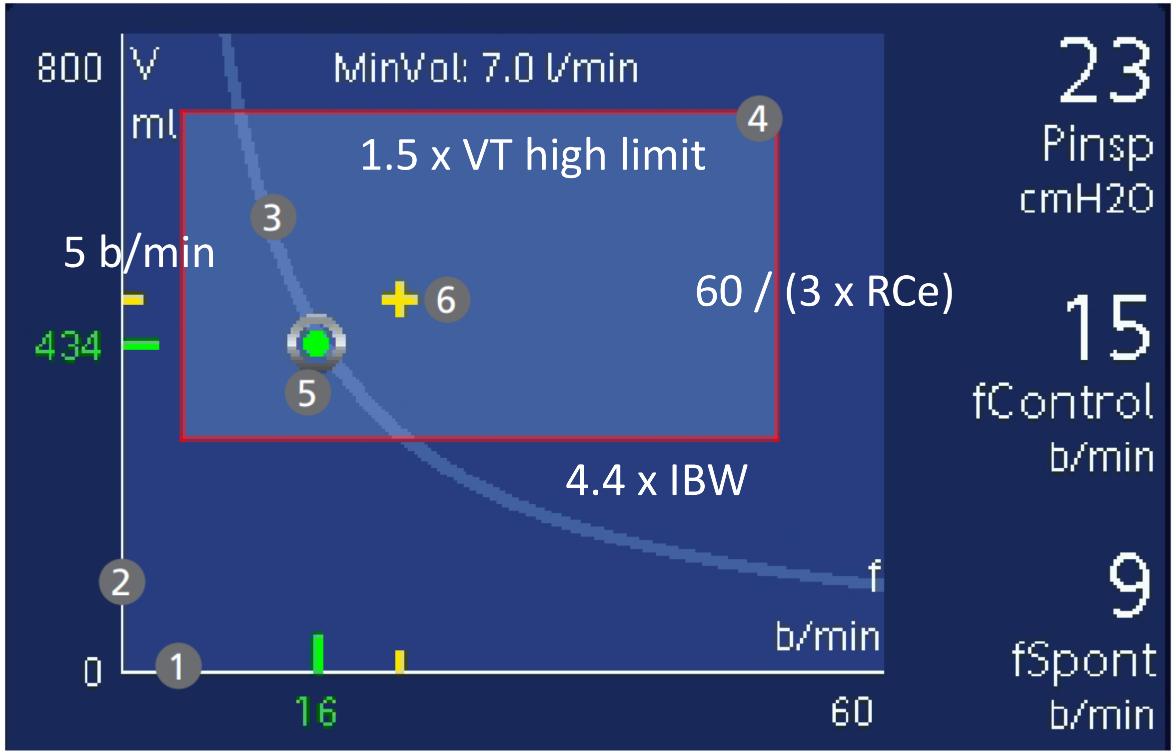


Figure 4: Security limits determined by adaptive support ventilation

Adaptive Support ventilation (ASV)

- 理想體重 (IBW) +每分鐘通氣百分比(%)



Weaning

*Phase 1 - **Screening***

- Stop deep sedation
- Reduce %MinVol (at most to 70%)

*Phase 2 - **Observation***

- RR < 30 breaths/min, Pinsp < 15 cmH2O, PEEP ≤ 8 cmH2O, Oxygen ≤ 40% for 30 min to 2 h, consider an SBT.

*Phase 3 - **SBT***

PEEP = 5 cmH2O, Oxygen = 30%
%MinVol = 25% for 30 minutes

Adaptive Support ventilation (ASV)

- Advantages

降低呼吸功，減少Lung injury

一種模式從頭到尾，方便操作

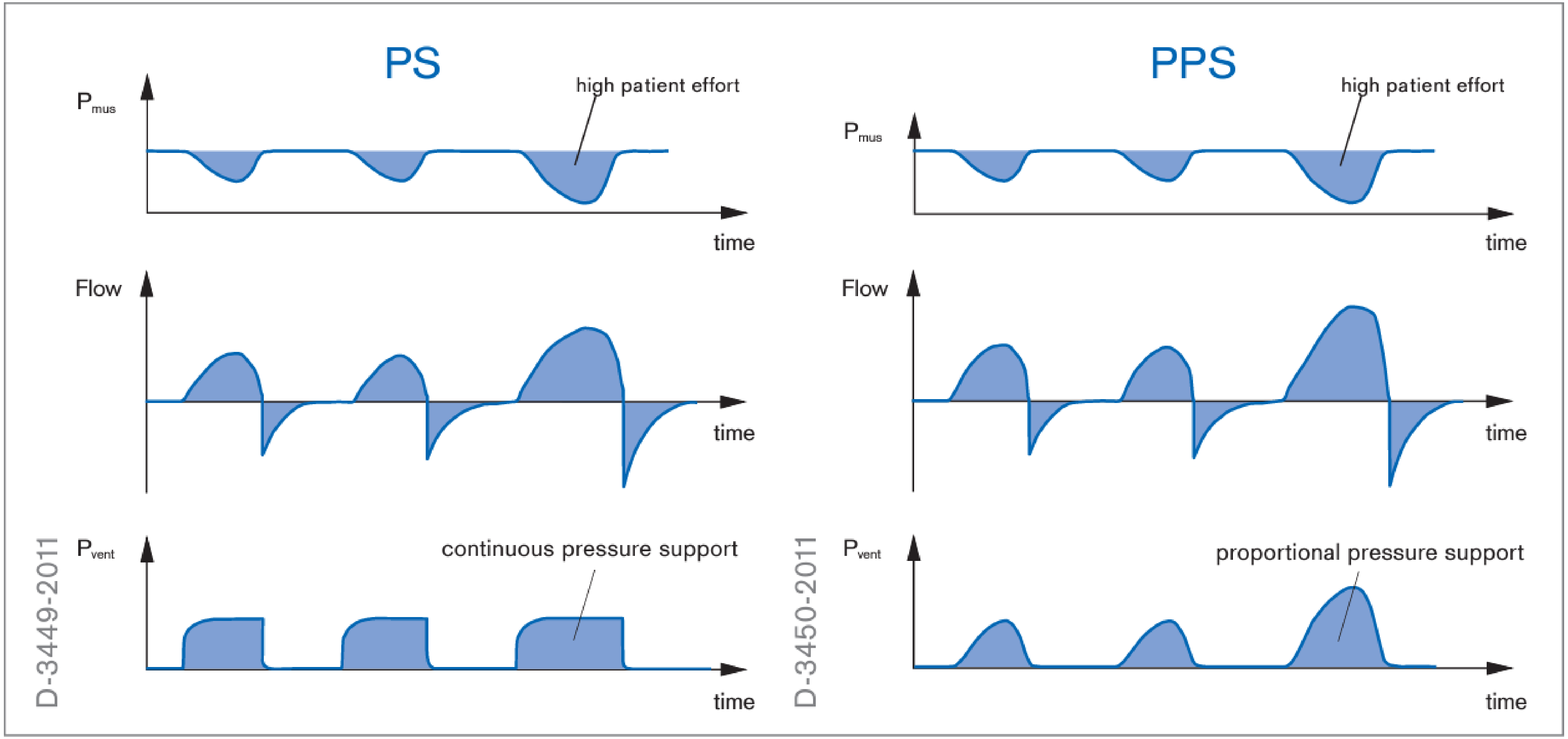
- Disadvantages

Table 3: Advantages and disadvantages of adaptive support ventilation

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

VT: Tidal volume; RR: Respiratory rate; auto-PEEP: Auto-positive end-expiratory pressure; I:E: Inspiratory:Expiratory

• Proportional Pressure Support (PPS)



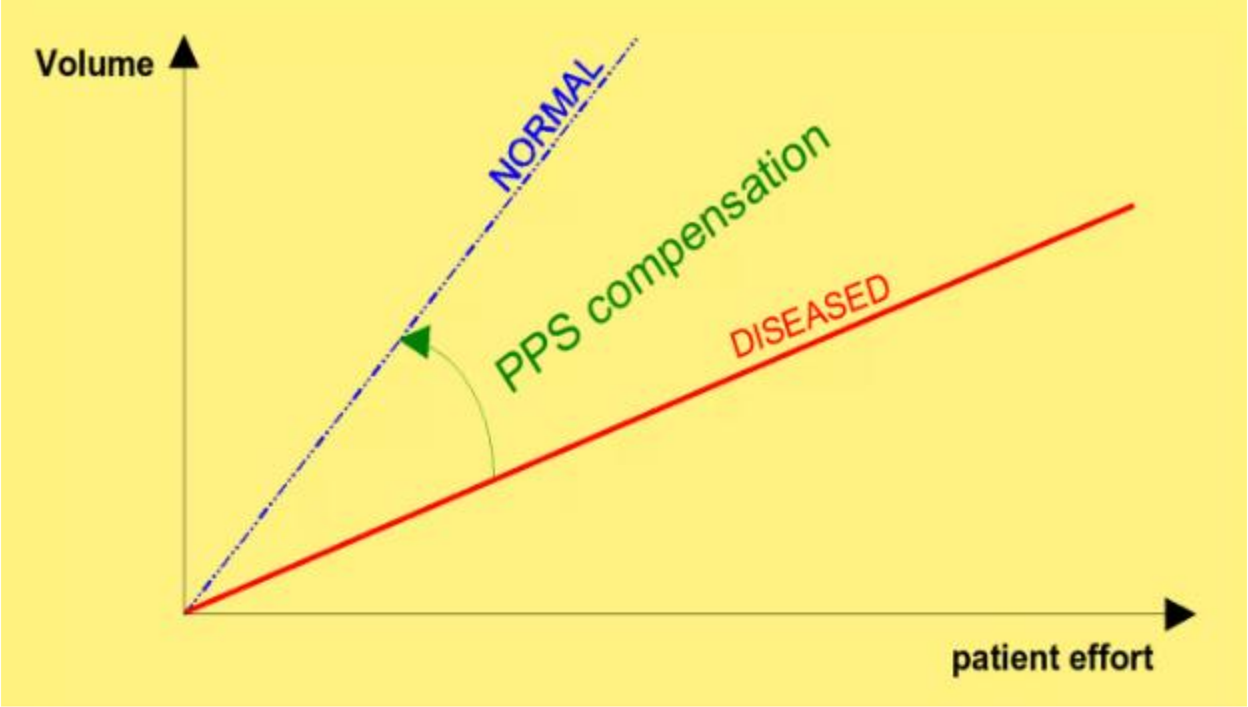
Proportional Pressure Support (PPS)

- Proportional Pressure Support (PPS)

$$\mathrm{P_{mus} + P_{aw} = \underline{V \cdot E_{rs}} + \underline{F \cdot R_{rs}} + PEEP_i}$$

Lung　　Airway

- Flow Assist= 80% resistance
- Volume Assist= 80% elastic



- Weaning
  - F.A. 降至 6 -8 cmH 2O/L/s
  - V.A. 降至 12 -14 cmH2O/L

Proportional Pressure Support (PPS)

Overcompensation of volume assist

- Tidal volume high
- Usage of expiratory muscle
- Flow rises too fast and drop abruptly

Overcompensation of flow assist

- Auto trigger, can’t correct by adjusting flow trigger
- May cause signs of volume assist overcompensation
- if clearly excessive of flow assist

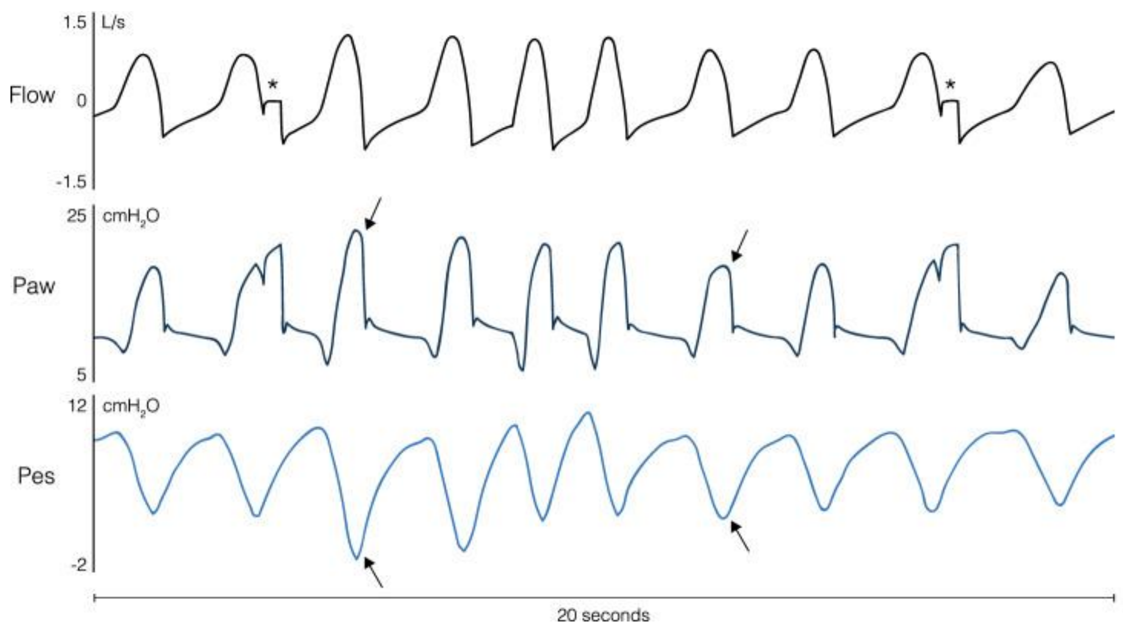
Proportional Assist Ventilation (PAV)

- Proportional Assist Ventilation (PAV)
- IBW、tube type (ETT/Trach.)、tube ID
- % Support
- Expiratory sensitivity (Range: 1 to 10 L/min)

約每4-10次呼吸，呼吸器自動監測氣道阻力、肺順應性和PEEP。

目標保持Pmusc around 5-10 cm H2O

Pmusc = Ptotal – Paw, Delta PAW= PIP-PEEP



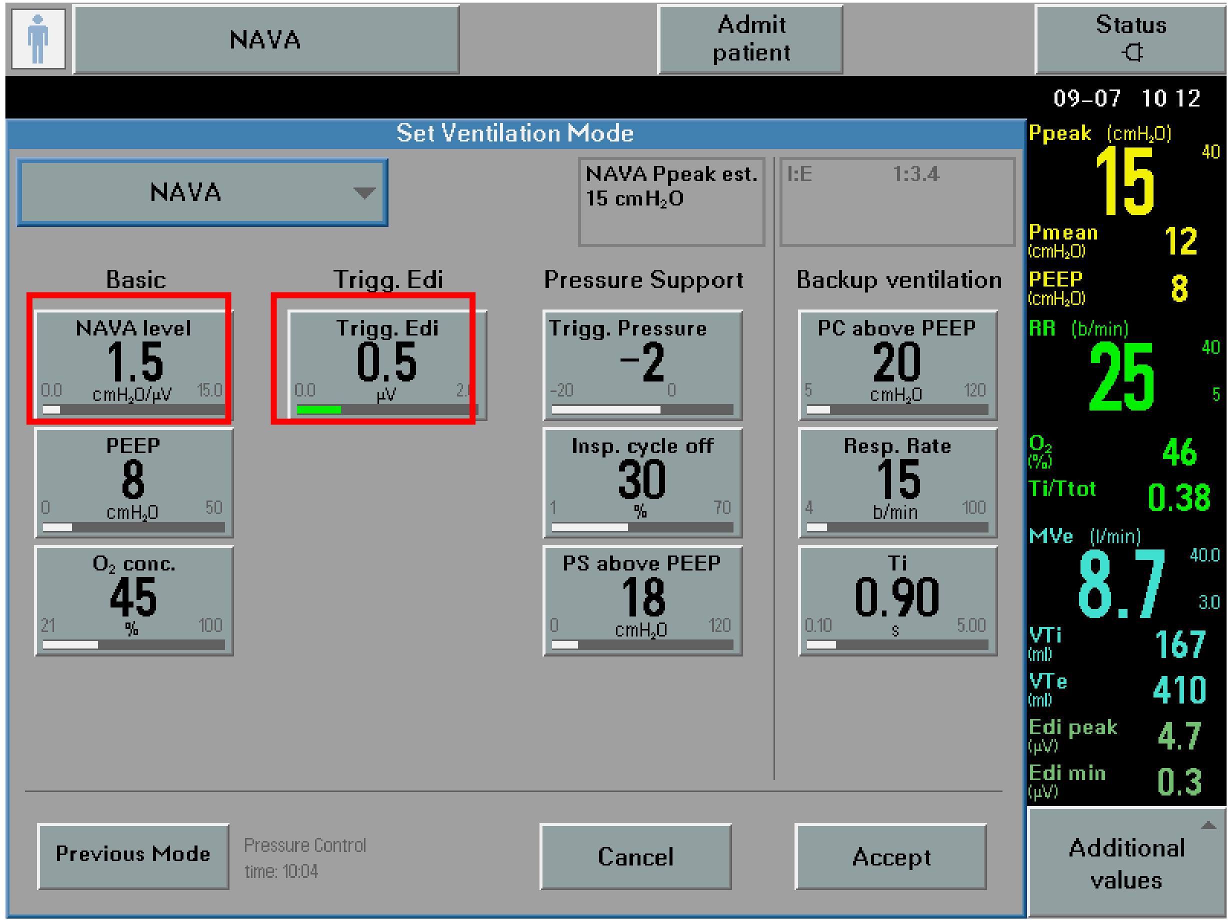
Endo/IBW 預期給予P

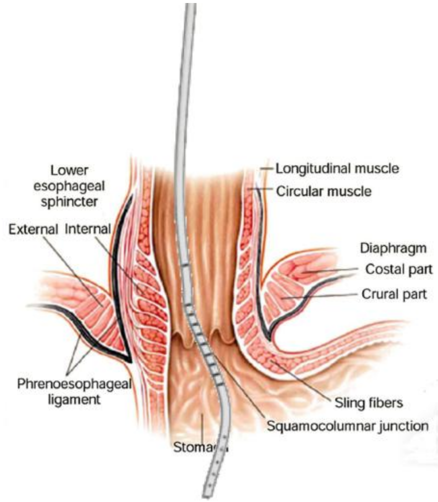
輔佐監測之數據

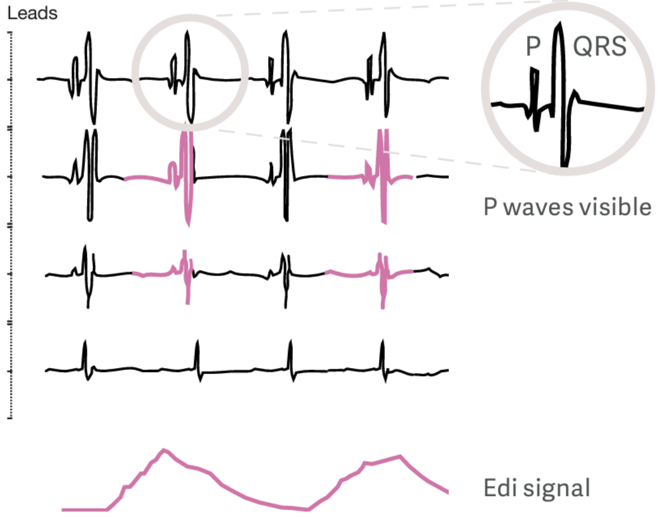
依據% 提供支持

Neurally Adjusted Ventilatory Assist (NAVA)

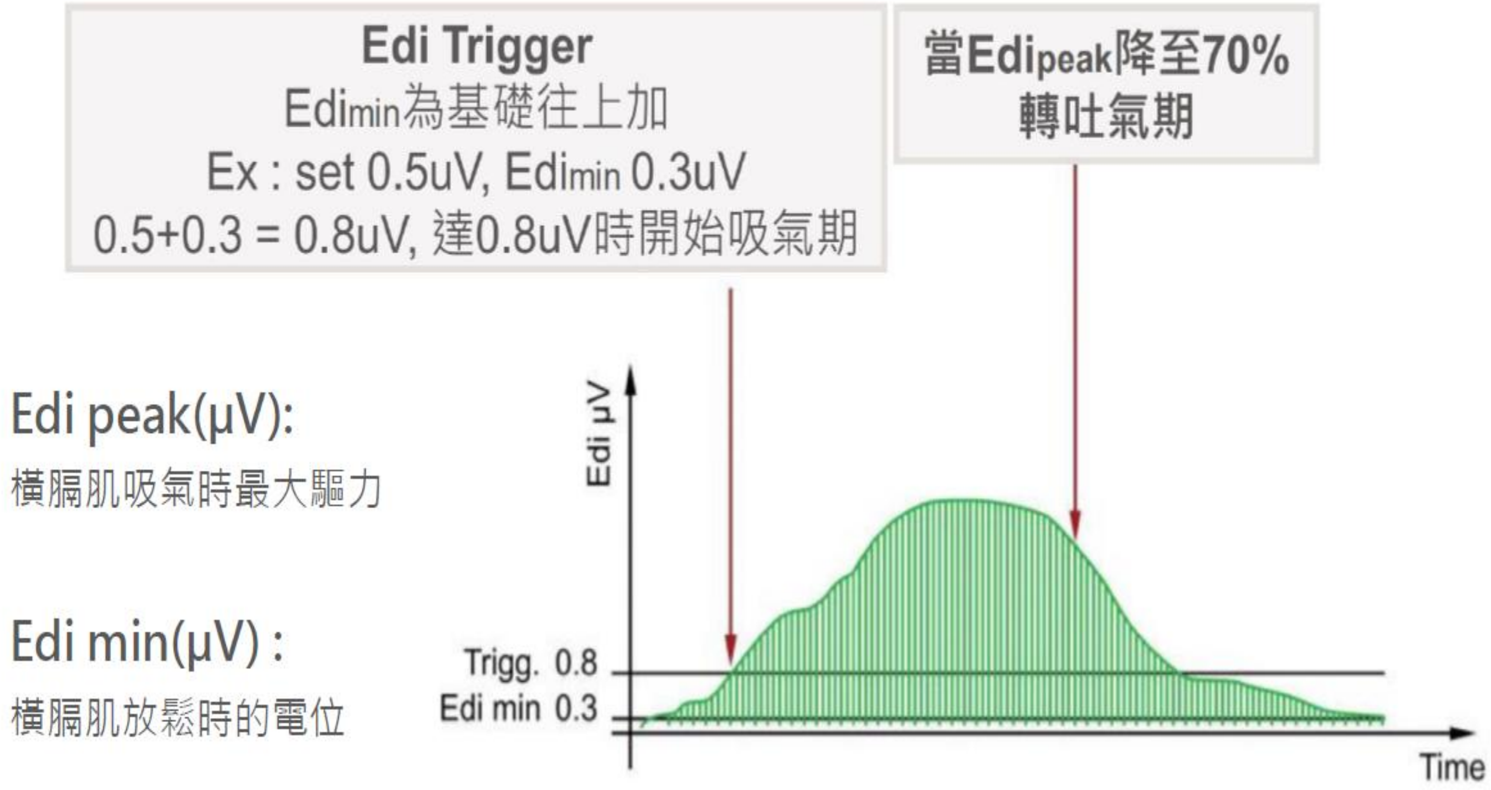
- Neurally Adjusted Ventilatory Assist (NAVA)







Neurally Adjusted Ventilatory Assist (NAVA)



Advantages

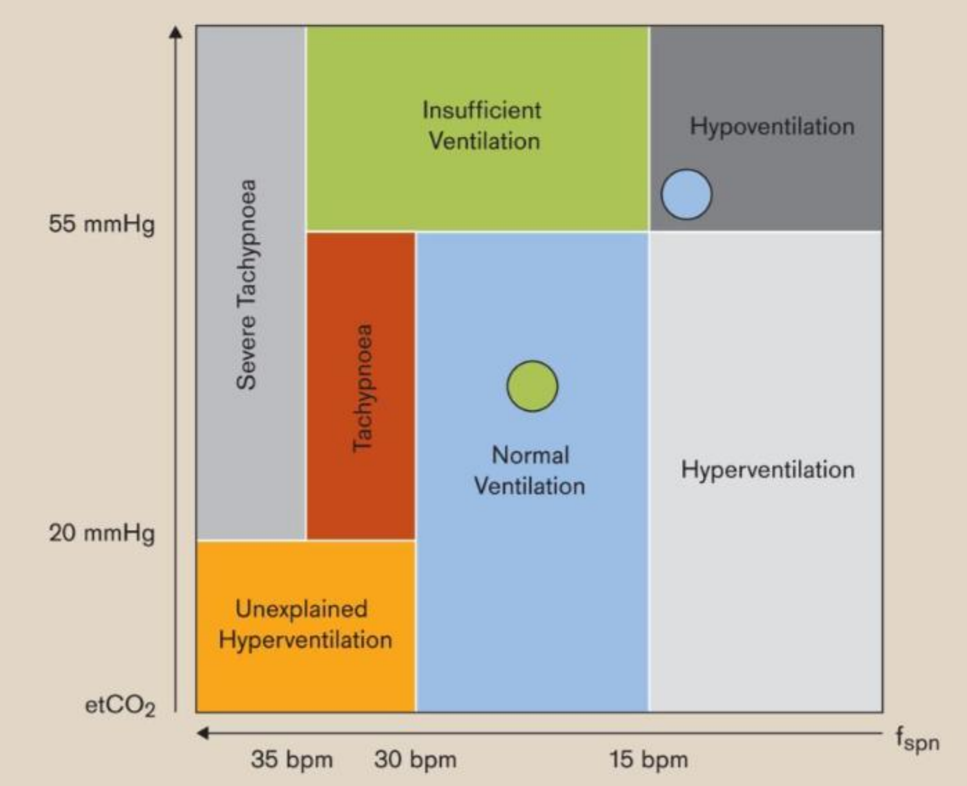
- Better synchrony
- Less over-support

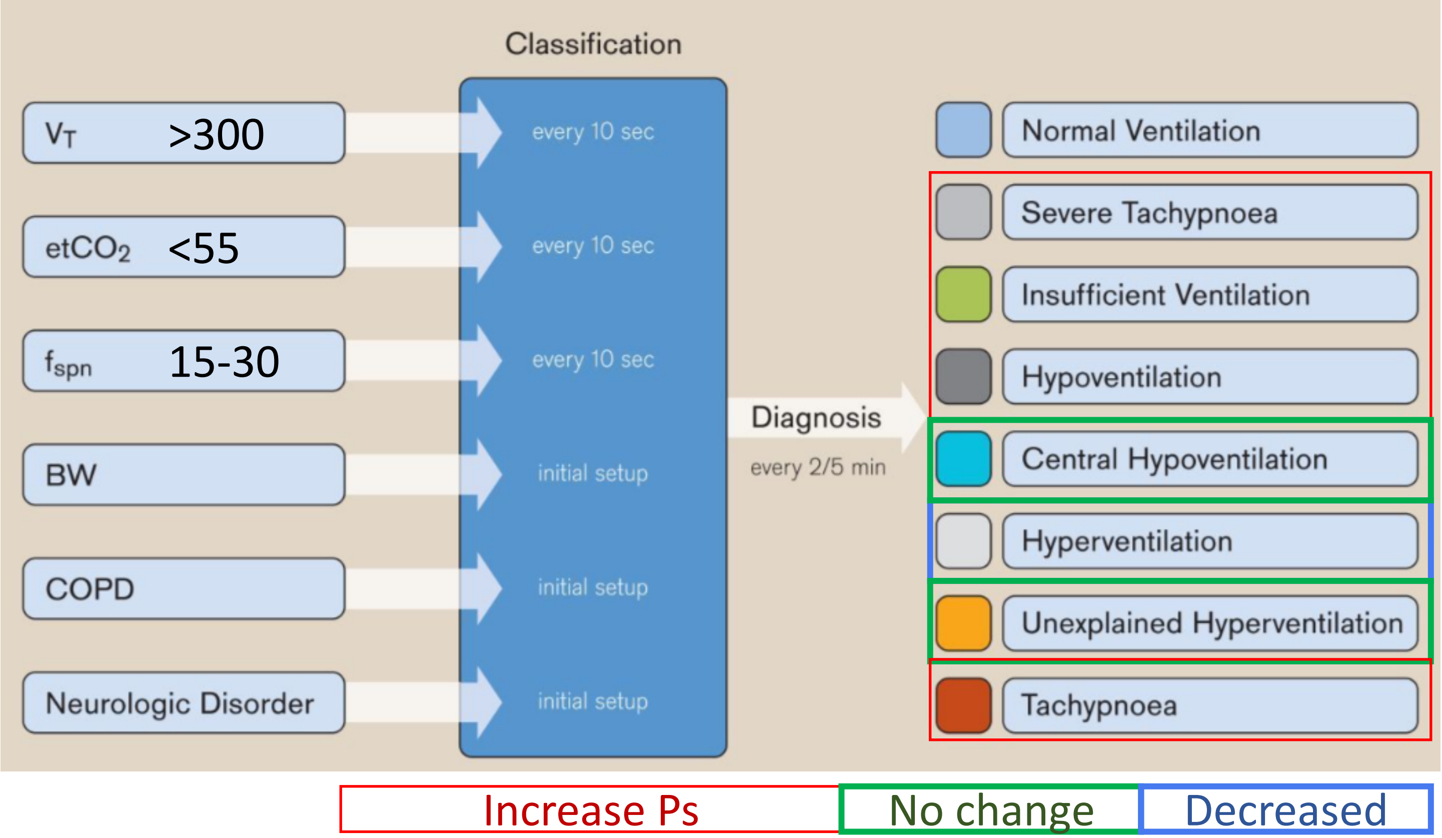
Disadvantages

- Special device
- Need Edi signal
- Position of Edi catheter

Smart Care

自動連續分析Spontaneous RR、Tv、EtCO2





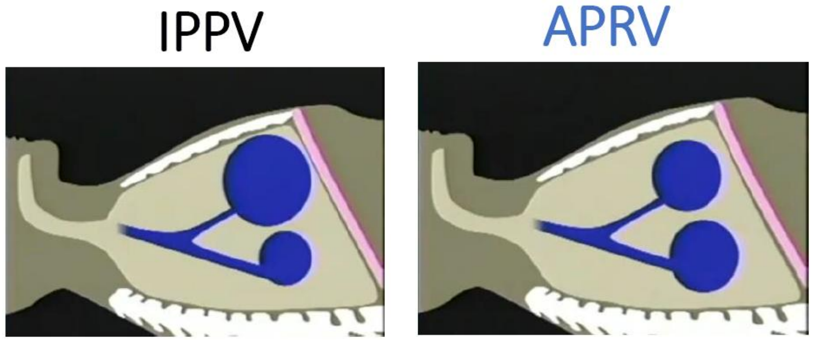
Airway Pressure Release Ventilation (APRV)

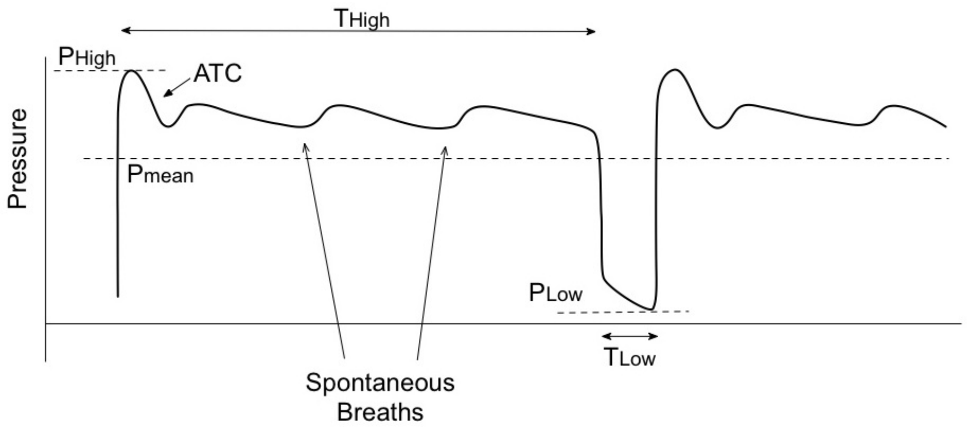
- Airway Pressure Release Ventilation (APRV)

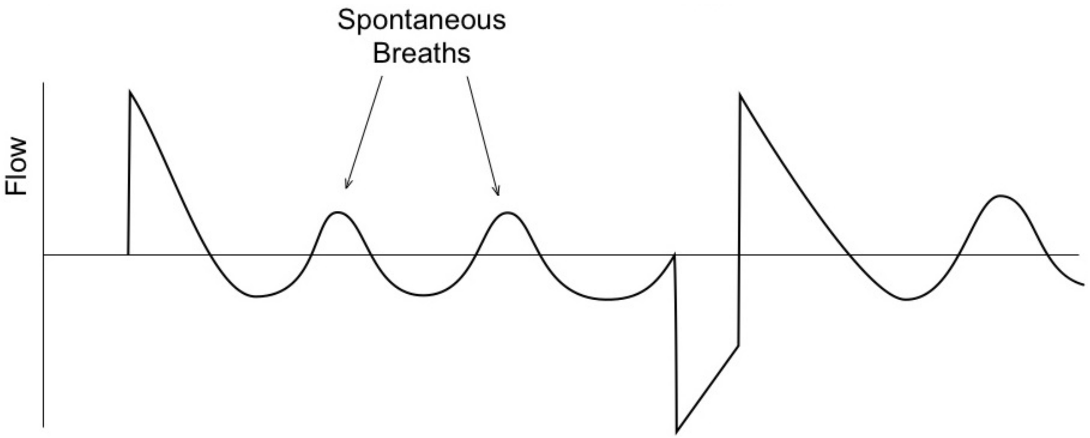
Inverse I:E ratio

Settings: Phigh, Plow, Thigh, Tlow

Disadvantages: hemodynamic unstable due to intrathoracic pressure, uncomfortable, fatigue during high pressure duration, CO2 retention







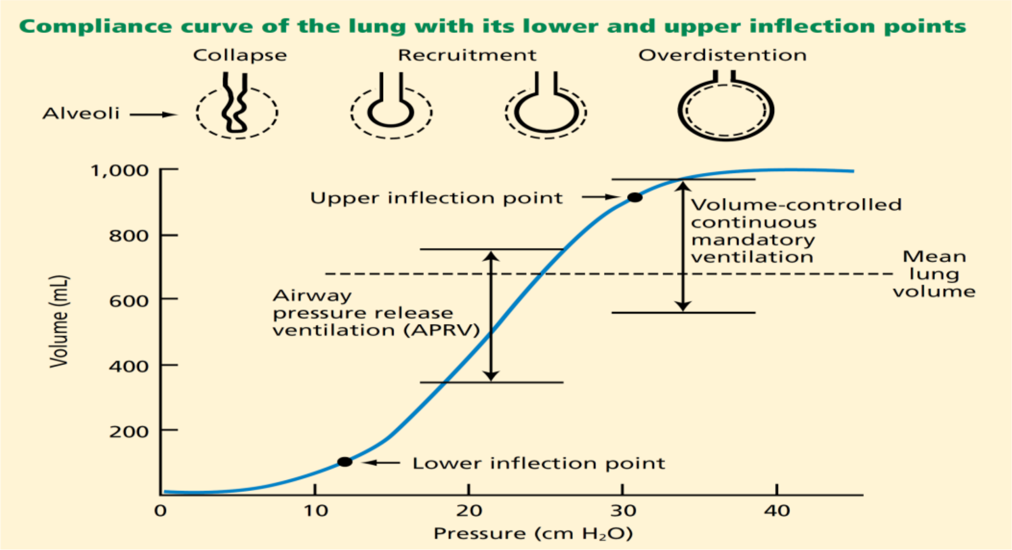
Airway Pressure Release Ventilation (APRV)

*PHigh at the PPlateau (or desired PMean + 3 cmH2O)

測定 P/V curve
upper inflection point 設定 Phigh
low inflection point 設定 Plow

↓

評估 T-PEFR(peak expiratory flow rate termination) > 50% and < 75%
建議：T_{high} 4 - 6 秒 T_{low} 侷限性肺疾病患設定 0.2 - 0.8 秒，阻塞性肺疾病患設定 0.8 - 1.5 秒



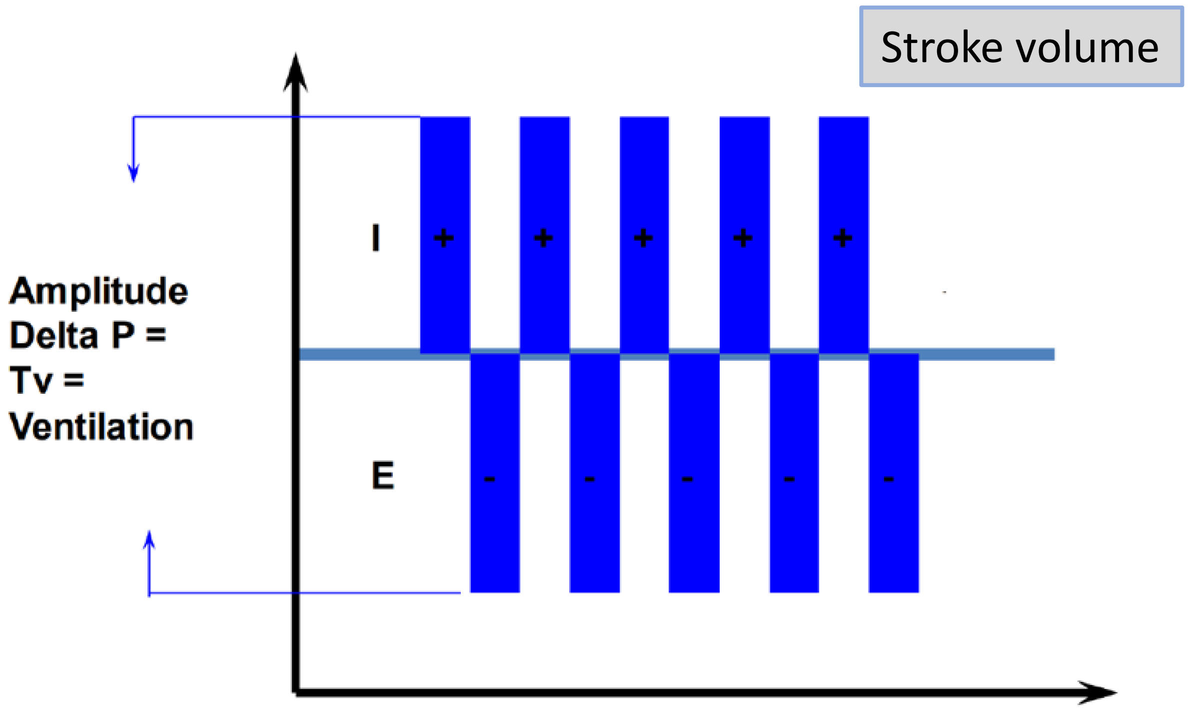
Airway Pressure Release Ventilation (APRV)

APRV 的脫離步驟： Drop and Stretch

1. $FiO_2 < 0.5$
2. 每次 2 - 3 cm H_2O 逐漸降低 P_{high}、P_{low}，$\triangle P$ 調至 8 ~ 12 cm H_2O
3. 調低 I：E 和呼吸頻率，注意病患的氧合及 $PaCO_2$ 變化
4. 當病患自主呼吸情況持續進步，呼吸器調整 CPAP 或 PSV 通氣模式使 $P_{high} \leq 16$ cm H_2O
5. $T_{high} \geq 12 - 15$ 秒 (APRV = 90 % CPAP)

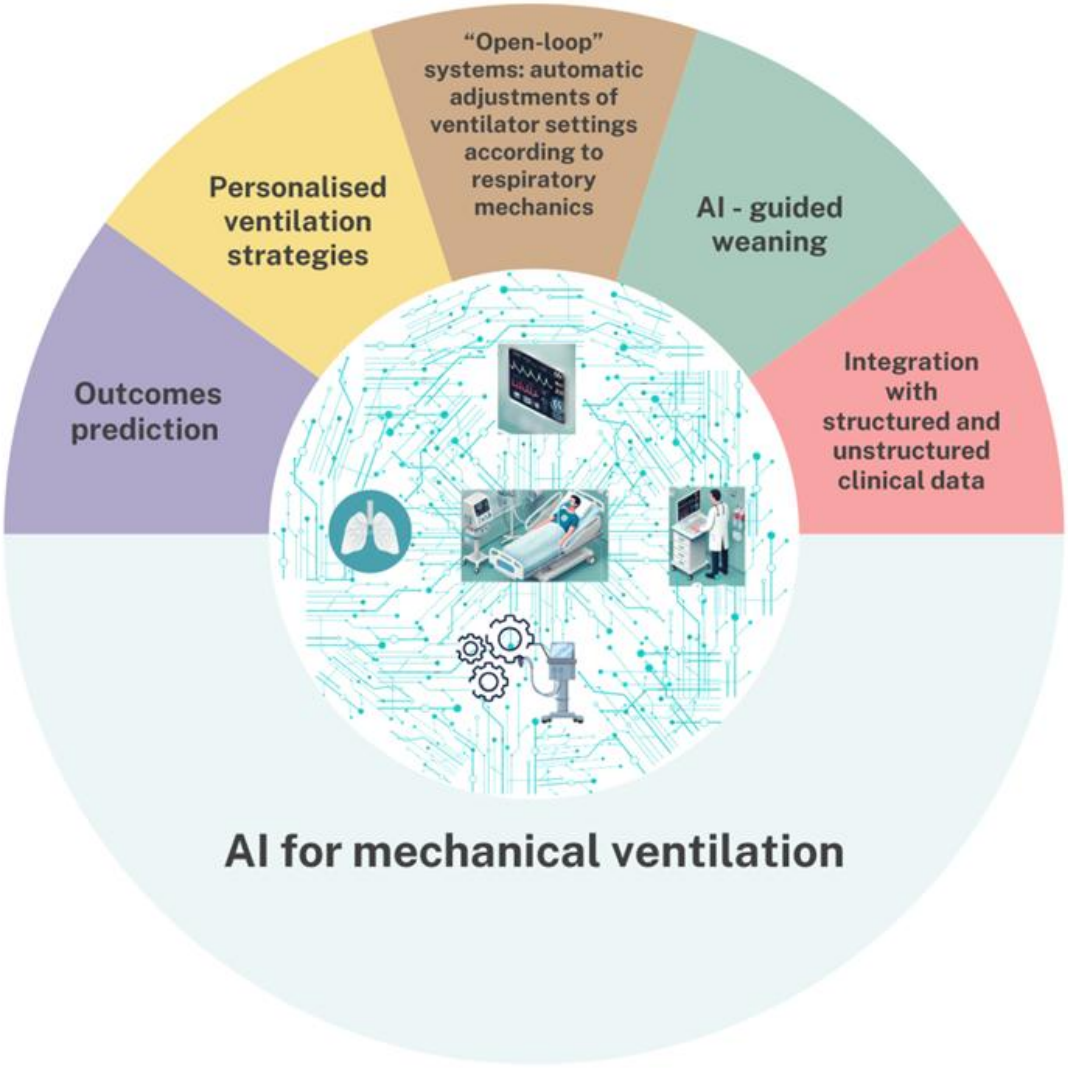
High frequency oscillatory ventilation (HFOV)

- Settings:
  - Amplitude(ΔP): (25%-100%)
  - Frequency: (5 Hz-15 Hz)
  - MAP: (6-25 cm)
- Follow up
  - MAP:根據PaO2及CxR胸廓擴張程度調整。目標胸廓在第8-9肋間。
  - Stroke volume: 根據 PaCO2 及高頻抖動程度調整。
- 當FiO2 < 40%、MAP <8-10H2O、且有穩定ABG數值時，才考慮轉回IMV



HFOV = CPAP with a wiggle

Artificial Intelligence for Mechanical Ventilation



Ther Adv Pulm Crit Care Med. 2024 Nov 11;19:29768675241298918. Artificial Intelligence for Mechanical Ventilation: A Transformative Shift in Critical Care

THANK YOU FOR YOUR LISTENING