Physiology and setting of mechanical ventilation

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Outline

- **呼吸器三大基本要素: trigger, limit, cycle**
- **呼吸器相關測量**

  Pplat 量測, driving pressure, resistance, compliance,

  autoPEEP, capnography, breath stacking, recruitment
- **Neuromuscular blockade (NMBA) usage and Patient Self-Inflicted Lung Injury (P-SILI)**

熱身一下

- 關於呼吸器調整，下列何者錯誤？

(A) 壓力控制模式(pressure control mode)需注意潮氣容積(tidal volume)。

(B) 容積控制模式(volume control mode)需注意氣道壓力(airway pressure)。

(C) 壓力支持模式(presure support ventilation)的吸氣時間是由呼吸器設定的。

(D) 以上皆非。

- 當呼吸器使用時，呼吸模式 ventilator mode 之選擇有其重要性，在單一模式下 Single mode，以下敘述何者為誤：

(A) AC mode 指的是呼吸器之驅動可由呼吸器來決定或病人帶動。

(B) pressure control ventilation mode (PCV mode) 使用時須設定，呼吸次數，吸氣目標壓力，及考慮吸氣時間，而決定吸氣變吐氣是由 tidal volume 來決定。

(C) pressure support ventilation (PSV) 必須完全由病人自行驅動。

(D) pressure support ventilation 決定由吸氣變成吐氣是經由設定吸氣氣流

- 加護病房中，常見呼吸器的使用於心肺衰竭的病人身上，有關吐氣末正壓(positive end expiratory pressure, PEEP)的設定及對血行動力學的影響，下列敘述何者錯誤？

(A) 對於血管內水分不足的病人，PEEP 會使血壓下降

(B) 對於重度心衰竭的病人，PEEP 會改善肺水腫

(C) 對於慢性阻塞性肺病急性發作、引起呼吸衰竭的病患，不應使用PEEP，以免加重吐氣困難

(D) 對於急性呼吸窘迫症候群(ARDS)病患，應使用高PEEP，避免肺泡塌陷

- 急性呼吸窘迫症候群(ARDS)病人，呼吸器設定使用吐氣末陽壓(PEEP)治療何者錯誤？

(A) 提供適當的氧合，降低 FiO2

(B) 防止肺泡塌陷，提供適當的組織氧合

(C) 增加肺部之功能肺餘量(FRC)

(D) 降低肺部之順應性(compliance)

- 下列何者不是 high flow nasal cannula 的生理效應？

(A) 提供足夠的氣流因應病患的換氣量

(B) 相較於 NIV 可以提供較高的病患舒適度

(C) 可以提供少量的 PEEP 效應

(D) 會增加 dead space

- High-flow nasal cannula (HFNC) oxygen therapy 在臨床上的應用愈來愈廣，下列何者非 HFNC 最重要的優點？

(A) 提供 warm and humidified air。

(B) 提供更大的吸氣輔助, 減少呼吸作功。

(C) 提供 fixed FiO2。

(D) 提供少許的 PEEP。

- 有關呼吸器設定 driving pressure 的描述何者為非？

(A) driving pressure 為 plateau pressure 減 PEEP

(B) 相同 driving pressure 下，plateau pressuree 愈高，死亡率愈高。

(C) 相同 driving pressure 下，PEEP 愈高，死亡率不會降低。

(D) driving pressure 大於 15cmH2O，死亡率會上升

Q. Pressure control model 和 pressure support model 最大不同點在於

A. Trigger

B. Limit

C. Cycle

D. 以上皆是

Q. 拔管後使用high flow nasal cannula 病患之評估，下列何者非主要監測指標

A. SaO_2
B. $PaCO_2$
C. Respiratory rate
D. ROX index [SaO_2/FiO_2)/Respiratory Rate]

- 下列有關PRVC (pressure-regulated volume control) 描述何者為”非”

A. Dual control, 偏向volume control

B. 基本上是一種 pressure control, 所以要好好設定pressure

C. Volume control 基礎下，設定volume 與 Ti

D. 優點在於讓呼吸器以最低pressure 下於設定時間(Ti)打入設定之體積 (volume)

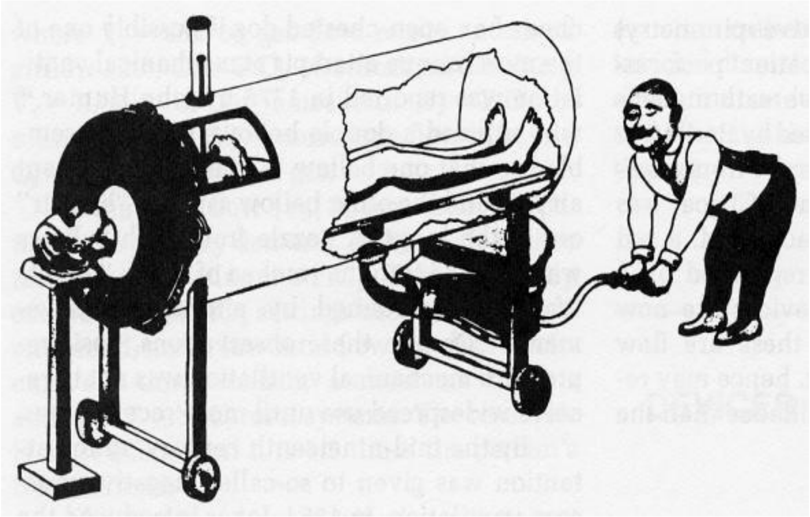
Outline

- **呼吸器三大基本要素: trigger, limit, cycle**
- **呼吸器相關測量**

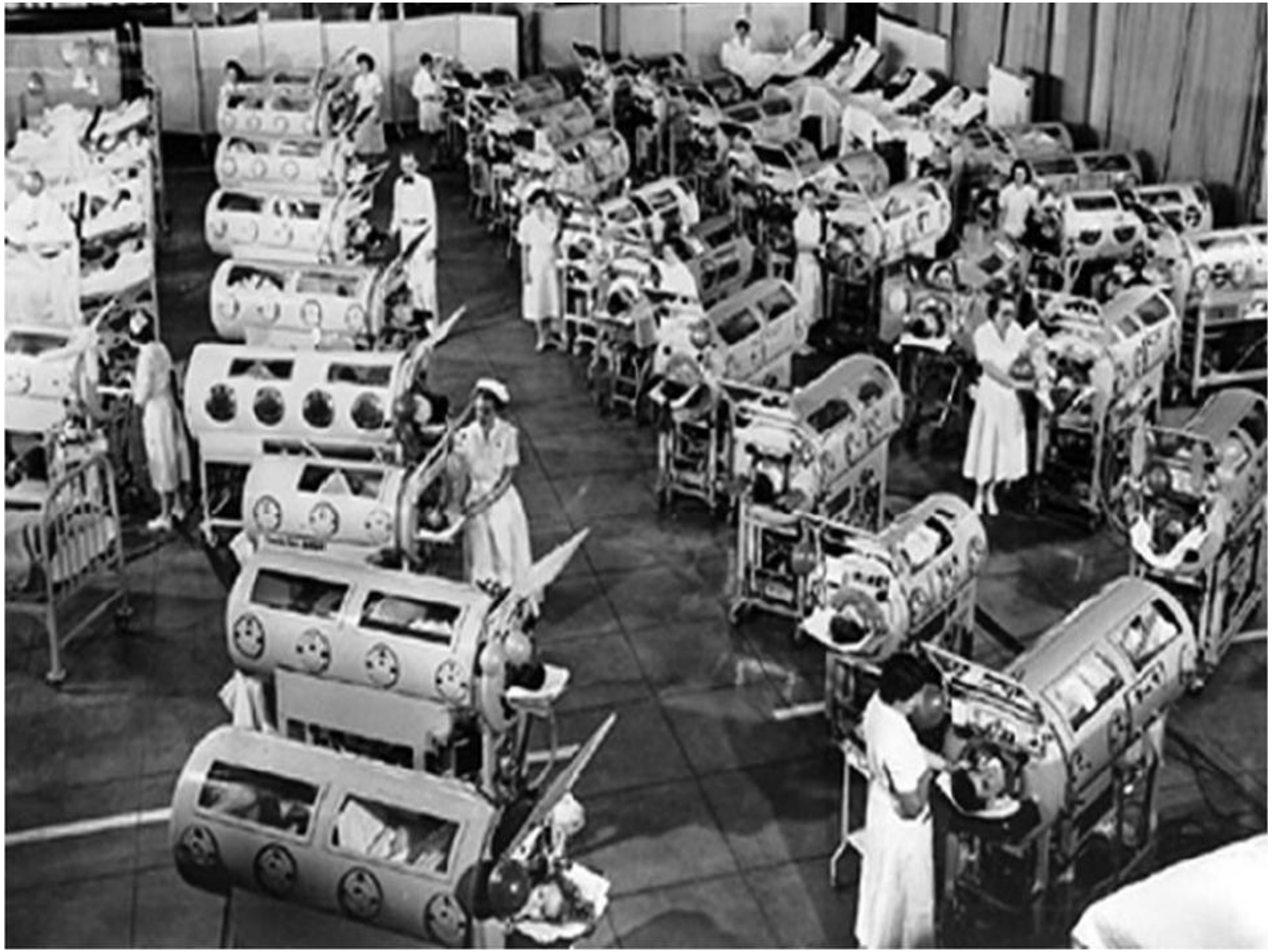
  Pplat 量測, driving pressure, resistance, compliance,

  autoPEEP, capnography, breath stacking, recruitment
- **Neuromuscular blockade (NMBA) usage and Patient Self-Inflicted Lung Injury (P-SILI)**

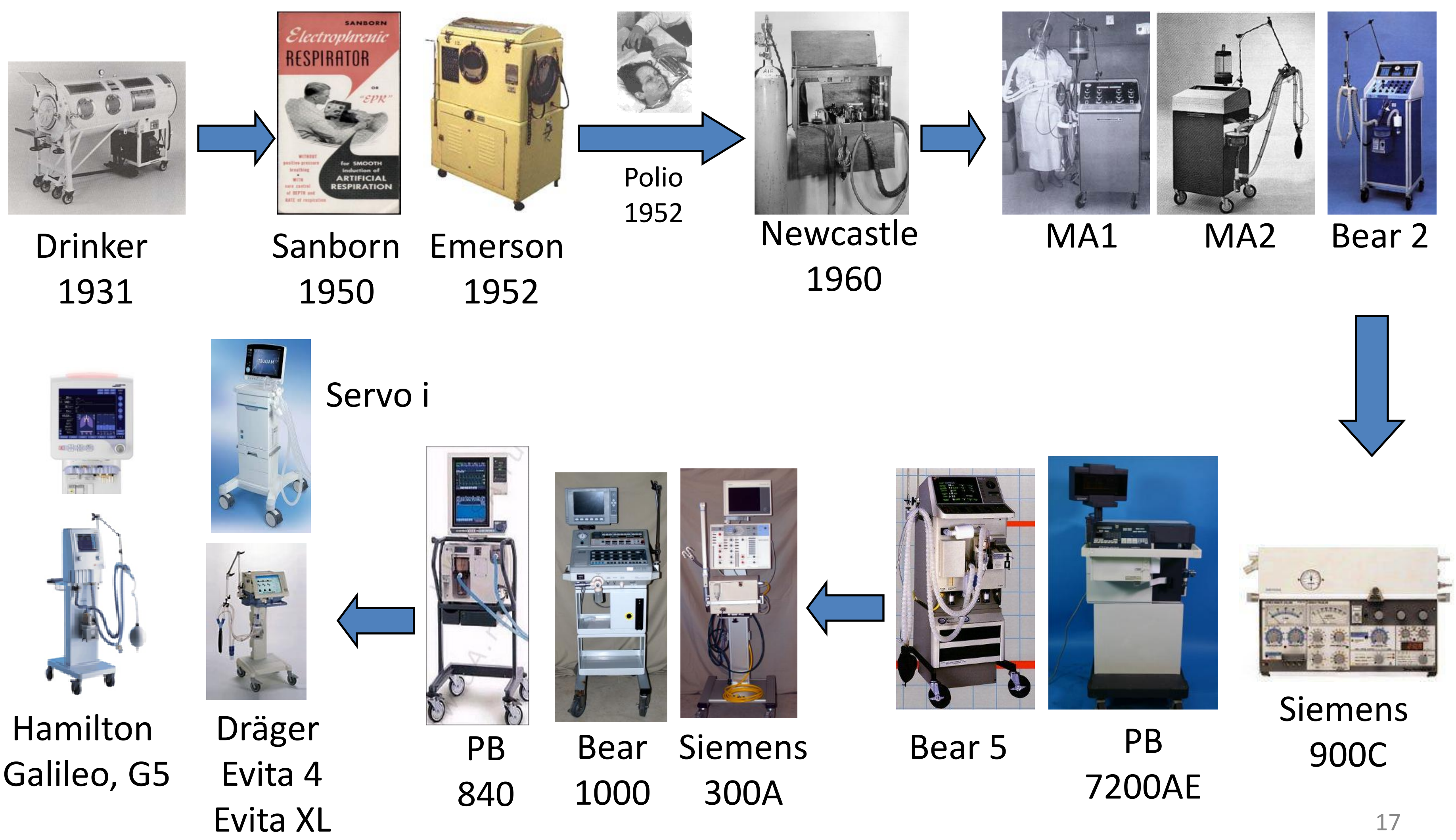
First workable iron lung designed by Woillez in 1876



Polio myelitis epidemic (1952)



Evolution of Ventilators



呼吸器：把氣打入肺部，再讓患者自己吐出來

怎麼打（呼吸器如何設定）

開始打氣的時間:何時開始打 (想打就打，病人想吸再打)

打氣的時間(打多久): 很快打或很慢打 (很快打氣太強不舒服，很慢打吸不到氣)

壓力(打的力量): 很用力打，輕輕打 (用力打氣太強不舒服，輕輕打打不完)

何時讓患者吐氣: 打完再讓患者吐、想吐氣就吐、快要吸不了就吐

Ventilator 三大基本要素

- Trigger
- Limit
- Cycle

- 決定何時開始打氣
- 決定用力的上限(時間/體積/壓力)
- 決定進入吐氣的時間點

開始打氣的時間:何時開始打 (想打就打，病人想吸再打)

打氣的時間(打多久): 很快打或很慢打 (很快打氣太強不舒服，很慢打吸不到氣)

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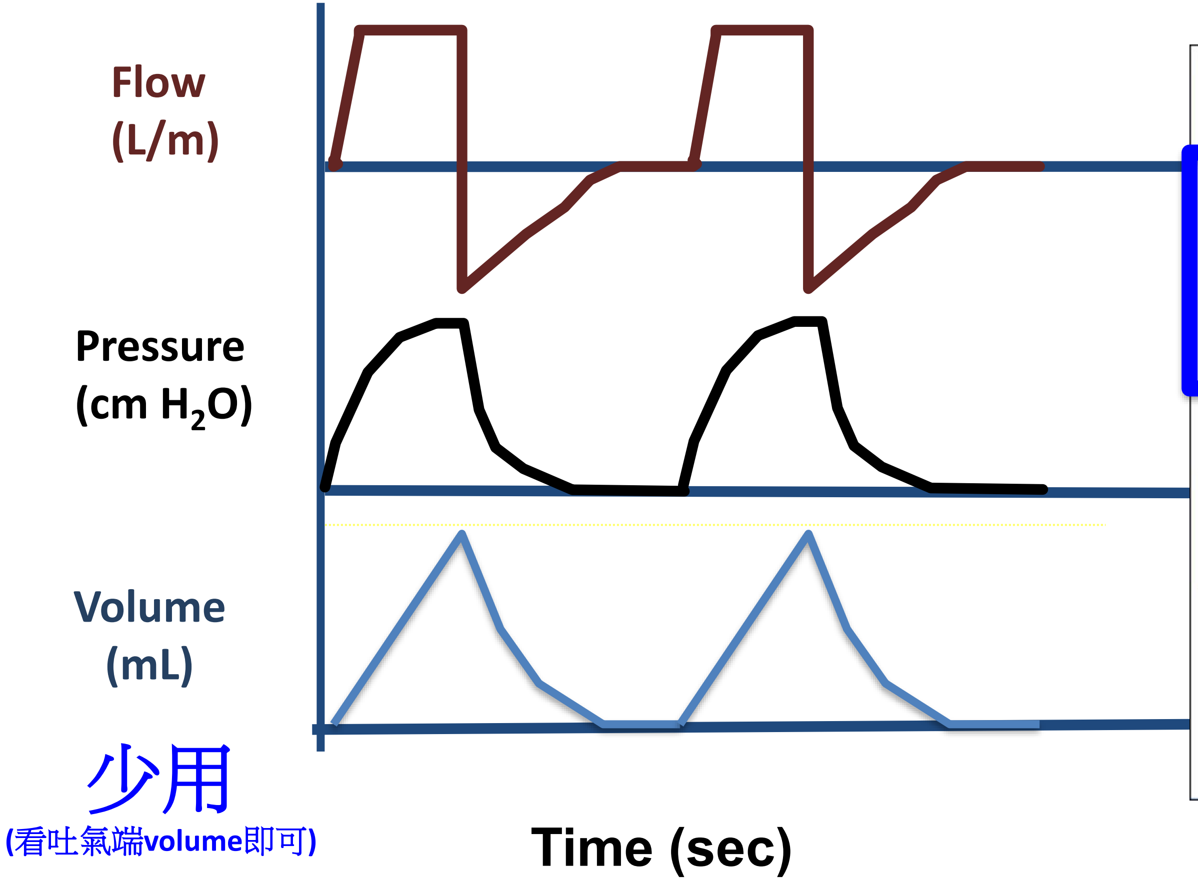
何時讓患者吐氣: 打完再讓患者吐、想吐氣就吐、快要吸不了就吐

Ventilator Graphic Waveform

1. Flow-time 2.Pressure-time 3.Volume-time (少用)

機器端直接打出來的是 flow ，但也會測量 pressure和 volume



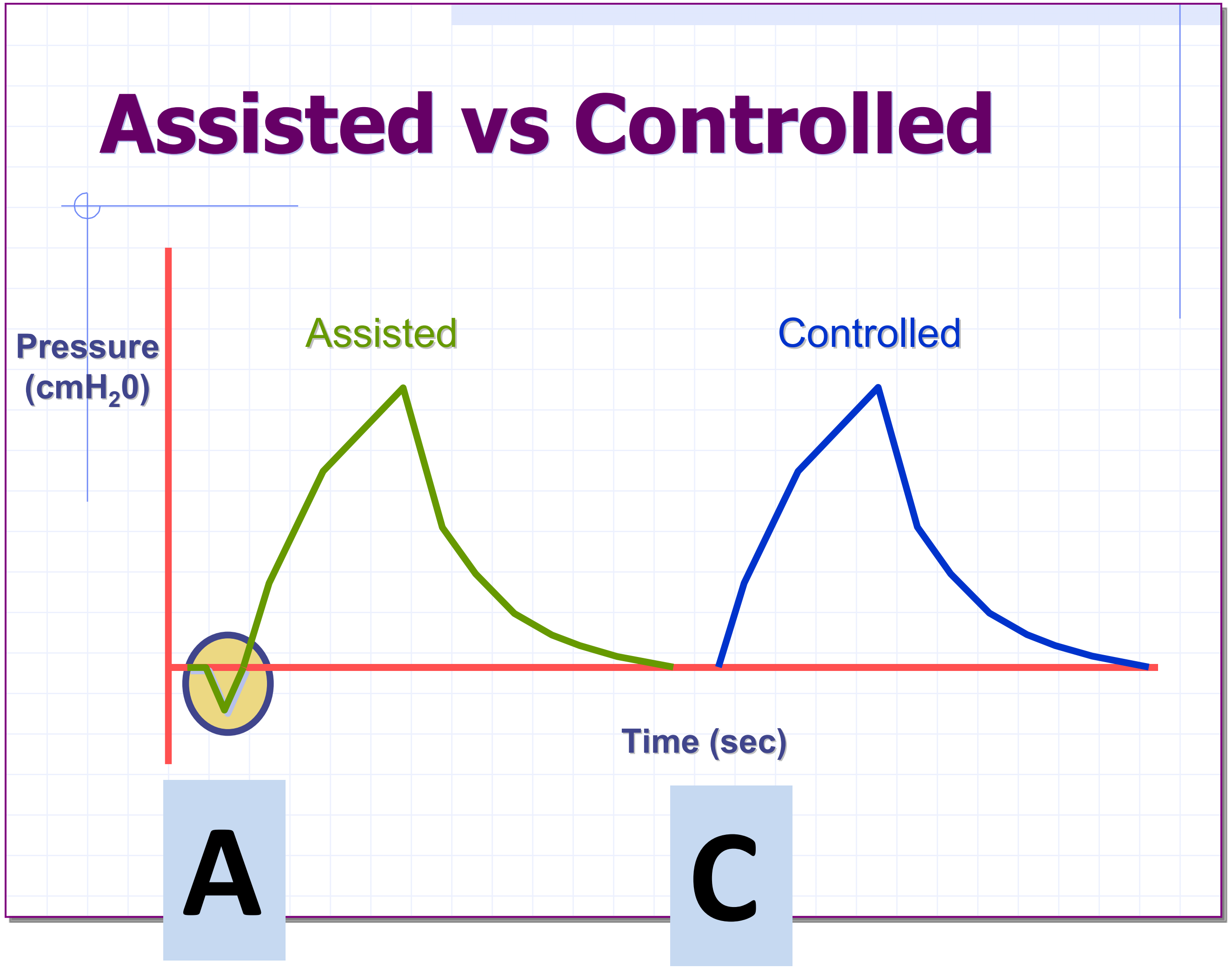
- Trigger
- Limit
- Cycle

C

A

Assisted: 病人想吸氣就打氣

Control: 依照內建時間打氣



Assisted ventilation

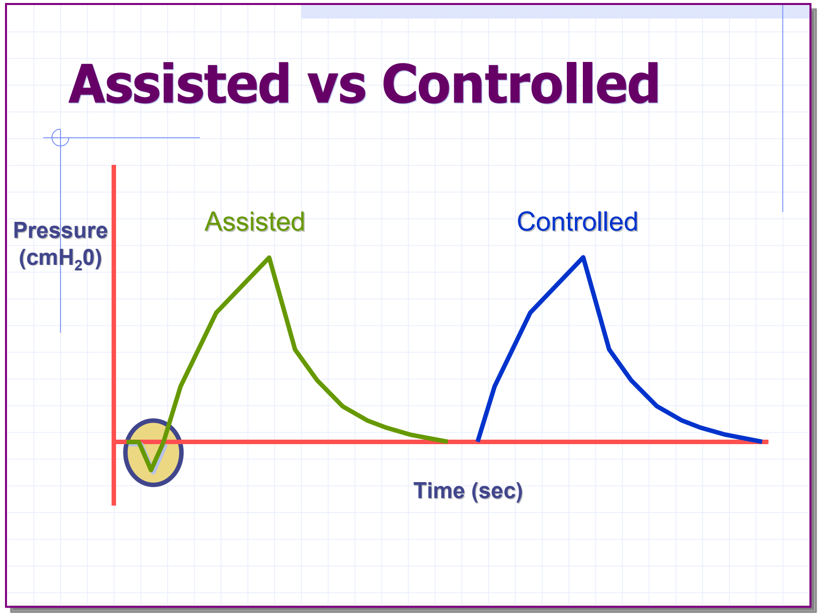
機器如何知道病人想吸氣

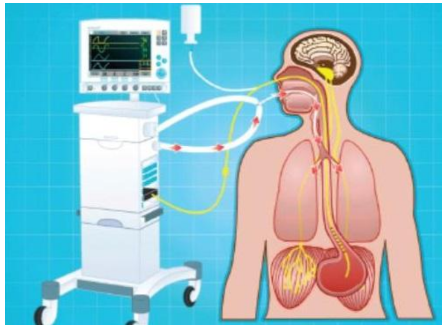
1.偵測到腦部訊號 (太困難)

2.偵測到呼吸肌肉(橫膈)訊號 **Neurally adjusted ventilatory assist (NAVA)**

3.偵測到實際吸氣引起之氣體流動變化 **Flow trigger** [很細微，所以看不到Pressure下凹]

4.偵測到實際吸氣引起氣體流動導致呼吸道壓力下降 **Pressure trigger**





Ventilator 三大基本要素

•Trigger	•決定何時開始打氣	C	A
•Limit	•決定用力的上限(時間/體積/壓力)		
•Cycle	•決定進入吐氣的時間點		

開始打氣的時間:何時開始打 (想打就打，病人想吸再打)

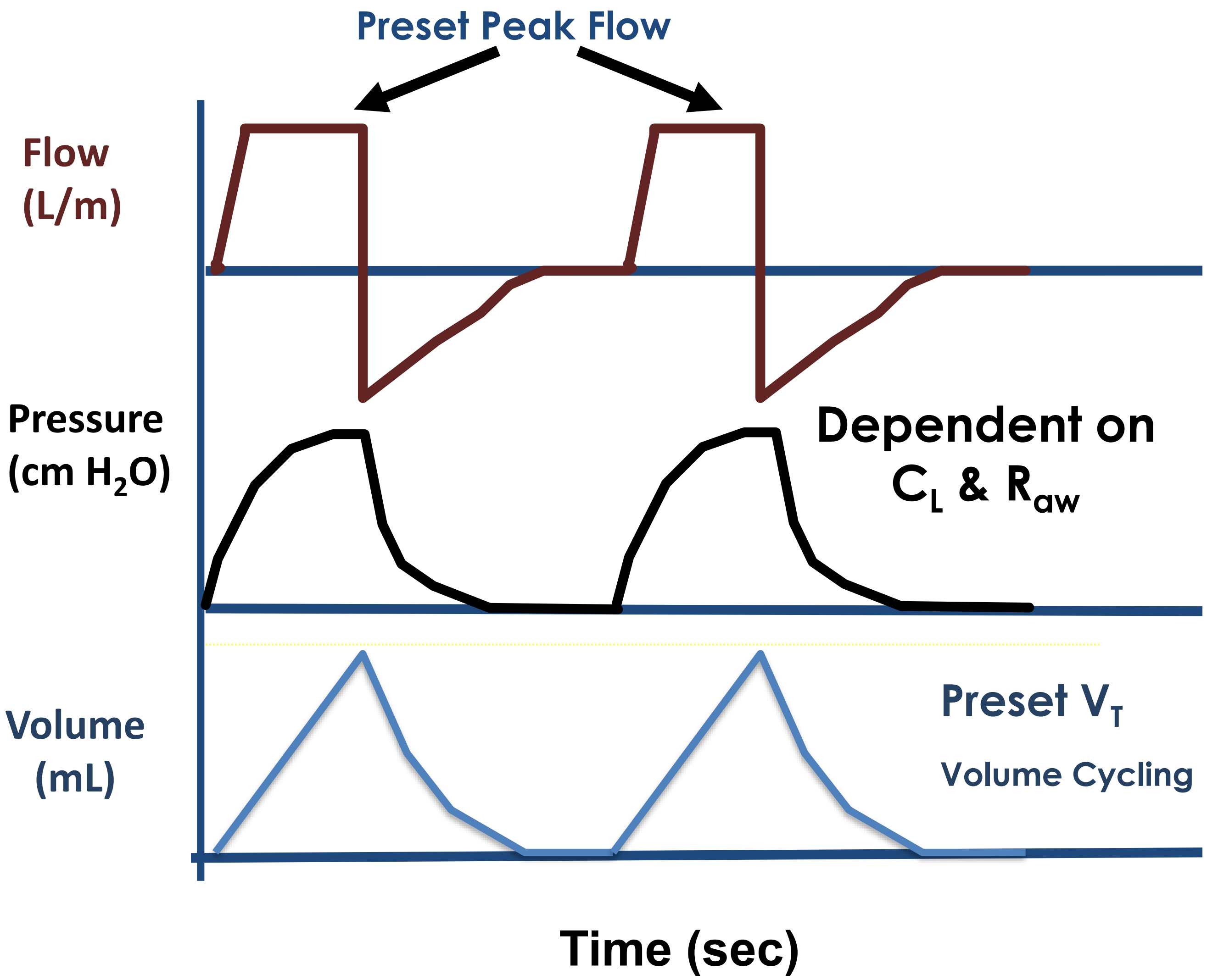
打氣的時間(打多久): 很快打或很慢打 (很快打氣太強不舒服，很慢打吸不到氣)

壓力(打的力量): 很用力打，輕輕打 (用力打氣太強不舒服，輕輕打打不完)

何時讓患者吐氣: 打完再讓患者吐、想吐氣就吐、快要吸不了就吐

Controlled Mode
(VC model, Volume controlled Ventilation)

Time triggered, Flow limited, Volume cycled Ventilation



VC

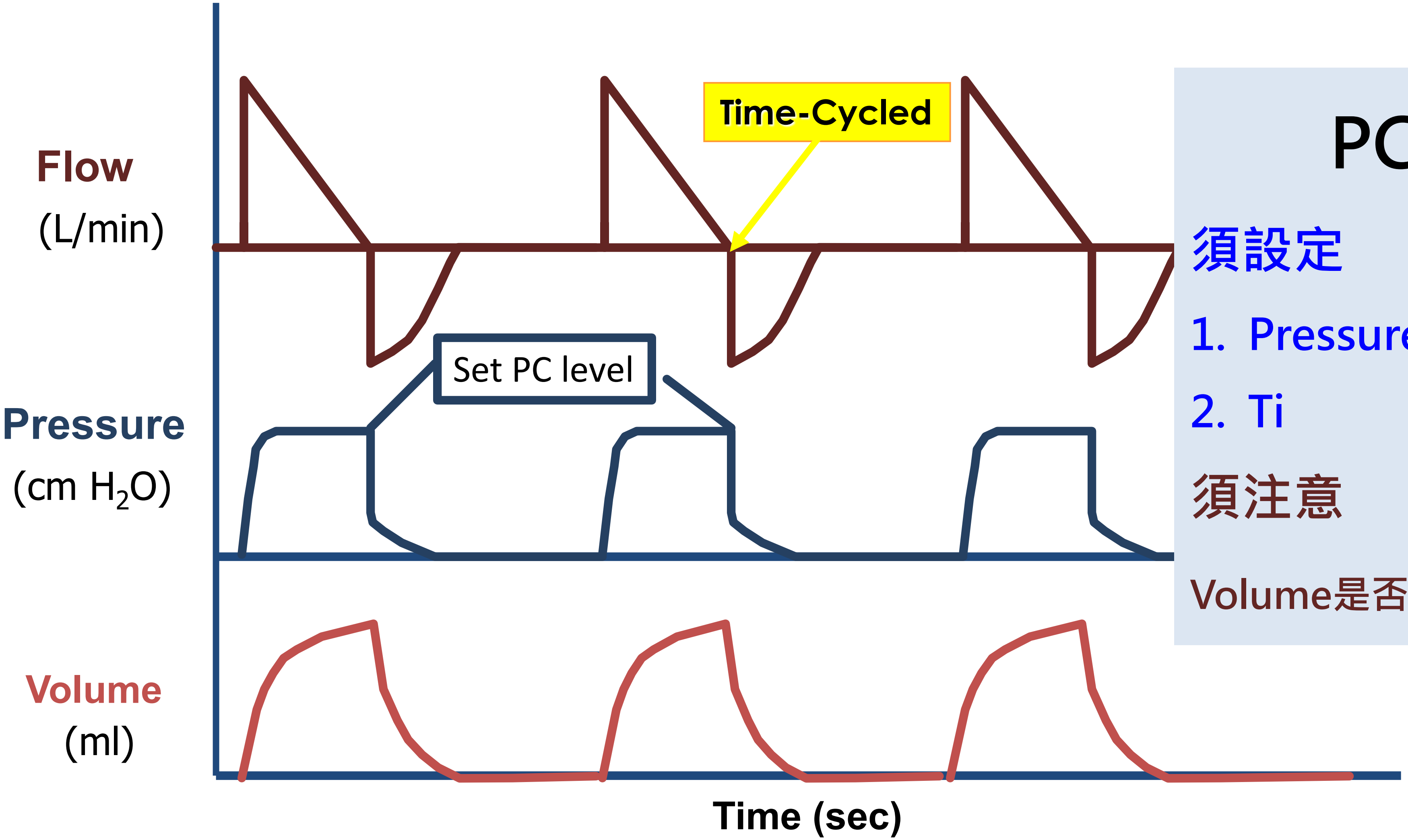
須設定

1. Volume
2. Flow

須注意

1. Pressure是否過大
2. Ti (吸氣期)是否過長

Controlled Mode (Pressure-Controlled)



PC

須設定

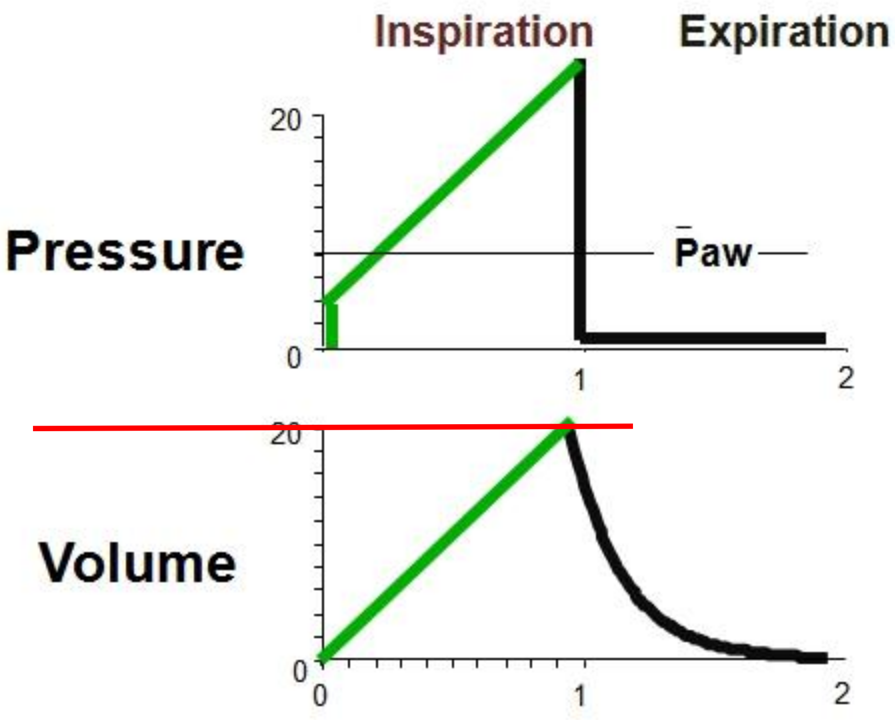
1. Pressure
2. Ti

須注意

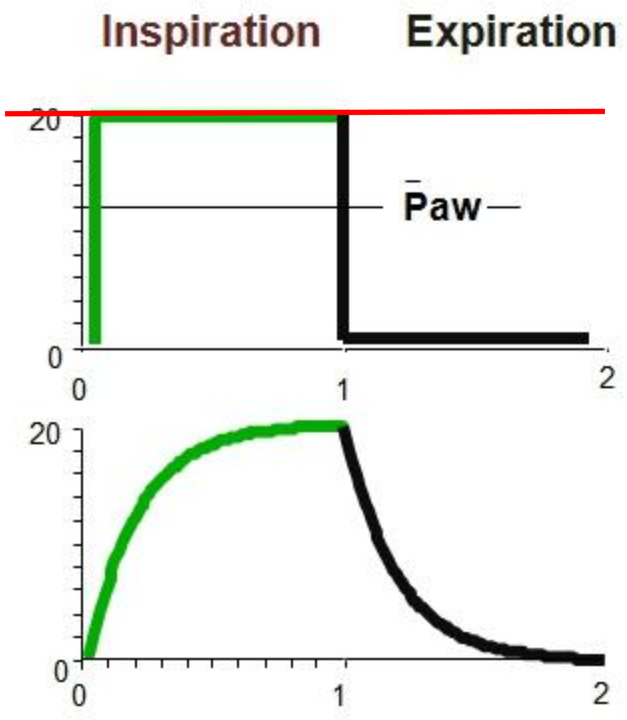
Volume是否過小/大

Time Triggered, Pressure Limited, Time Cycled Ventilation

Volume Control



Pressure Control



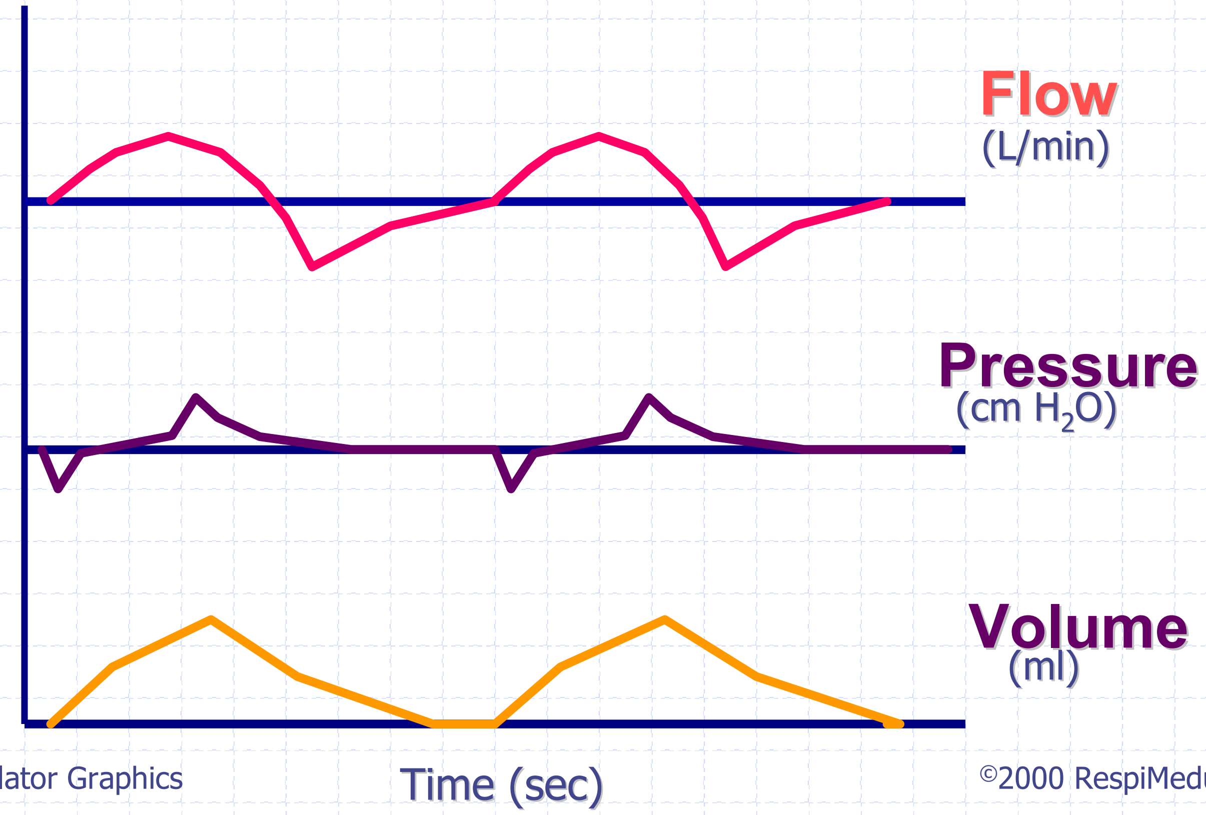
內建模式：打到設定的量(體積)就不打，直接進入吐氣

缺點：壓力有可能會過大

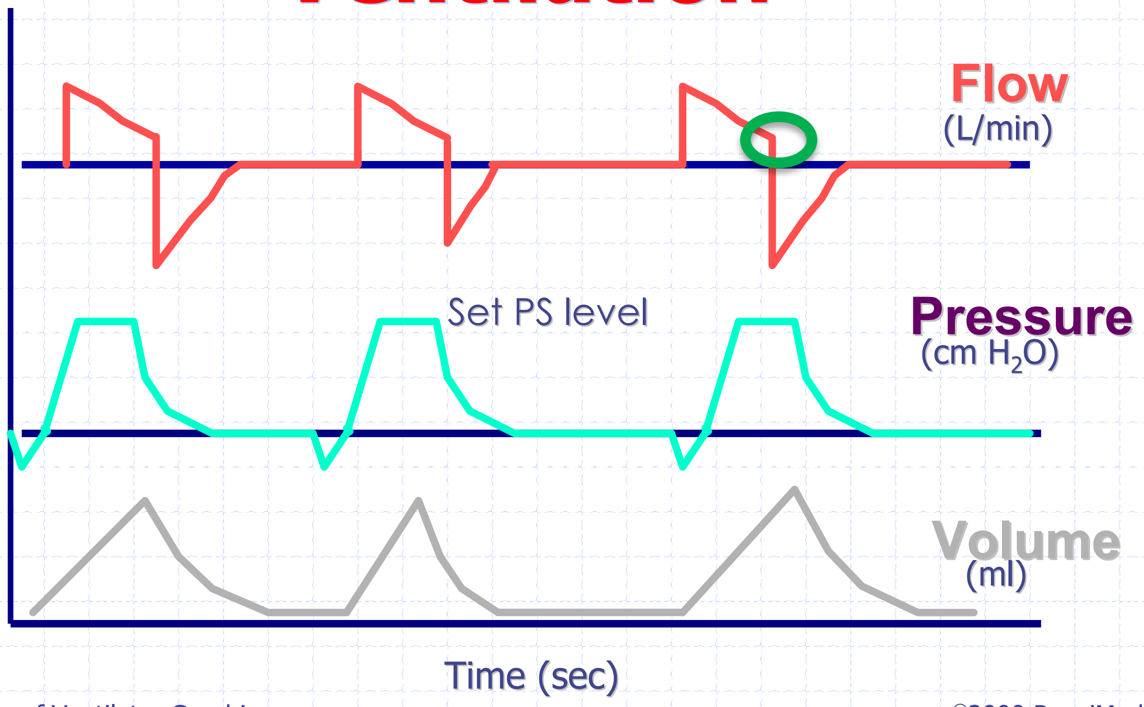
內建模式：打到設定的壓力就以這個壓力打一段設定的打氣時間

缺點：(量)體積變動很大，可能不夠（低的壓力氣會打不進去）。

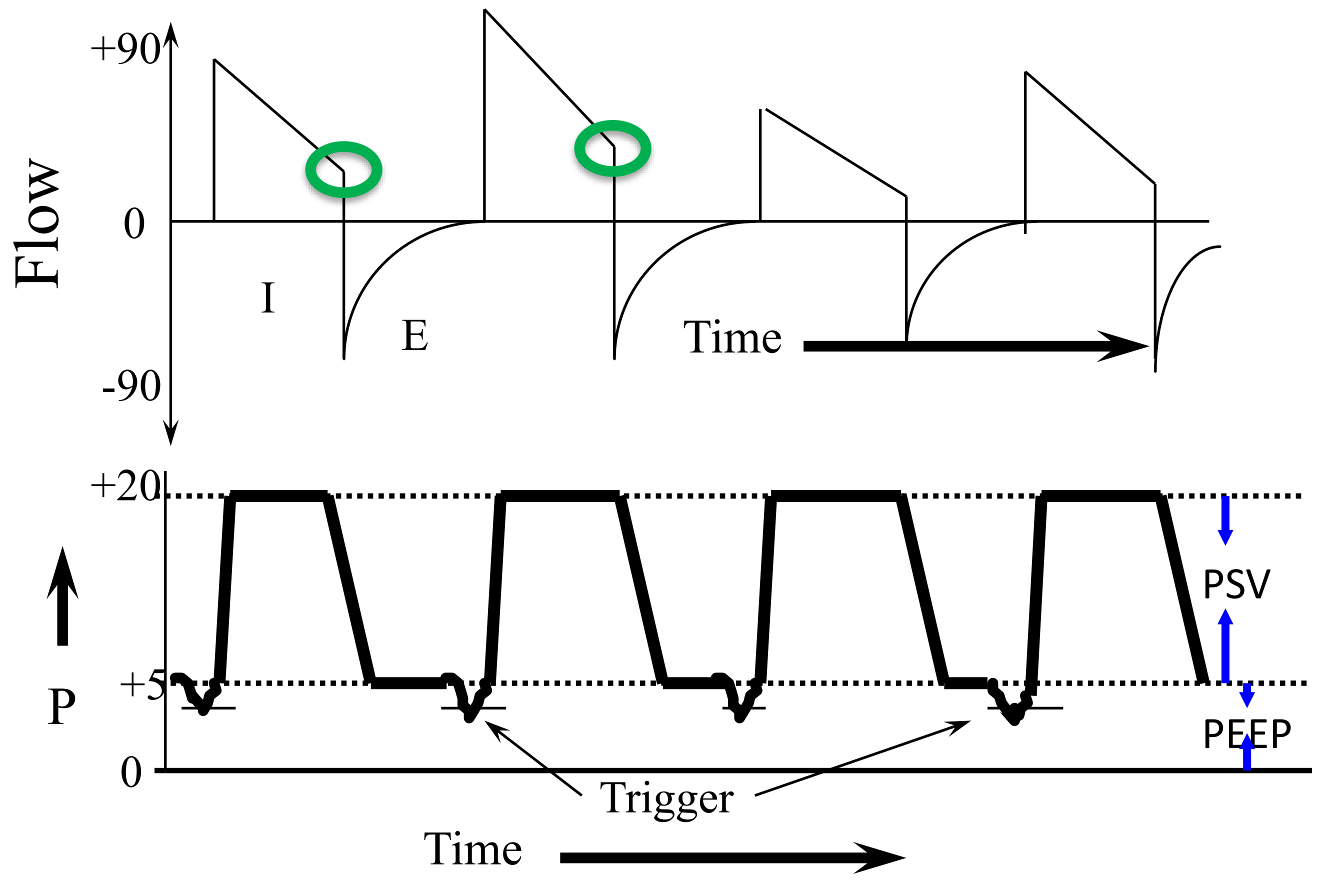
Spontaneous Breath



Pressure Support Ventilation

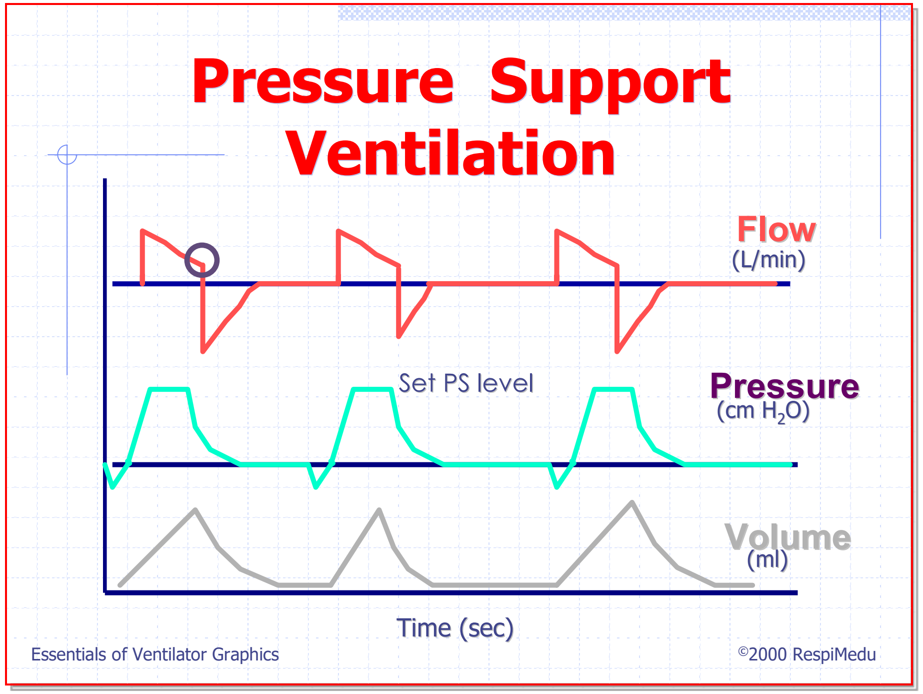


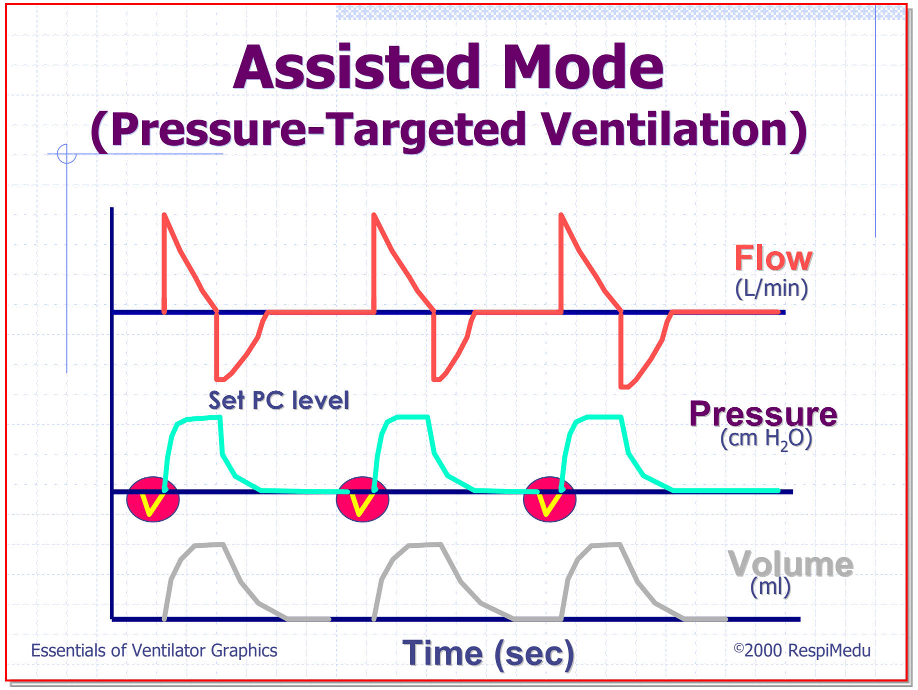
Pressure Support Ventilation (PSV)



吸氣➔吸到差不多飽了就停了(cycle)

Pressure support vs. pressure controlled





相同點: **limit, 都是 pressure limited (打到設定的pressure)**

不同點: cycle

pressure control 打一段時間所以是time cycle

pressure support 則是flow下降就停止打氣，所以是 flow cycle

- 關於呼吸器調整，下列何者錯誤？

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(B) 容積控制模式(volume control mode)需注意氣道壓力(airway pressure)。

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(D) pressure support ventilation 決定由吸氣變成吐氣是經由設定吸氣氣流

- 呼吸器於壓力輔助 (pressure support) 模式時 ，發出低呼吸量警告 (low minute ventilation alarm)，下列各變化何者可能性最低？

(A) 肺栓塞

(B) Midazolam 增加

(C) 氣道分泌物增加

(D) 肺水腫

Q. Pressure control model 和 pressure support model 最大不同點在於

A. Trigger

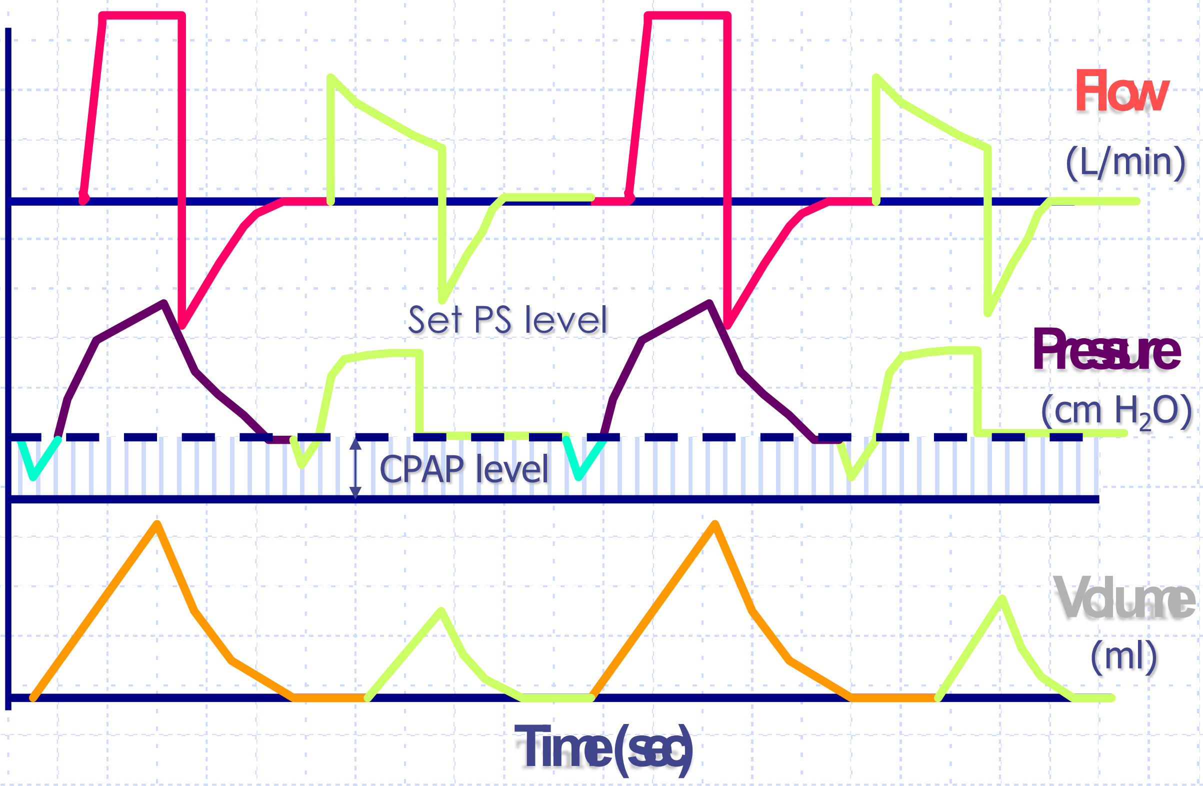
B. Limit

C. Cycle

D. 以上皆是

Mixed Pressure support and Controlled ventilation (VC/PC)

SIMV+ PS
(Volume-Targeted Ventilation)



SIMV: Synchronized Intermittent Mandatory Ventilation (VC)
PS: Pressure support

PC, VC → dual control

VC

須設定

1. Volume
2. Flow

須注意

1. Pressure是否過大

2. Ti (吸氣期)是否過長

PC

須設定

1. Pressure
2. Ti

須注意

Volume是否過小/大

有沒有可能Volume control 但又可兼顧Pressure不會過大

PRVC (pressure-regulated volume control)

到底是V/C 還是 P/C, 要設定什麼

Volume control ➔設 Volume + flow

Pressure control ➔設 Pressure + Ti

PRVC (pressure-regulated volume control) ➔設 Volume + Ti

Q1. 到底是volume control 還是 pressure control

Q2. 如果是volume control, 那 flow 誰決定

Q3. 如果是pressure control, 那pressure 誰決定

PRVC ➔ Dual control

i. 設定一個目標volum和給機器一個時限(Ti)

ii. 機器會持續量測pressure，然後自動調整flow/pressure

iii. 目的在以最小的Pressure於設定的Ti內拿到設定的volume

[T rise ➔多快到peak。設太短給氣太快病患會覺得很嗆；設太長氣太慢病患會覺得吸不到氣，此外Trise太長剩下時間短，但又要把氣打完pressure不得不稍微提高]

PRVC (pressure-regulated volume control) 到底是V/C 還是 P/C, 要設定什麼

- PRVC 算 dual control，偏向V/C，但會另外給一個 Ti，pressure 就交給機器；最後目標在目的在以最小的Pressure於設定的Ti內拿到設定的volume。

有沒有可能Volume control 但又可兼顧Pressure不會過大

PRVC, VC+, APVcmv

APVcmv

Adaptive Pressure Ventilation

-Control Mode Ventilation

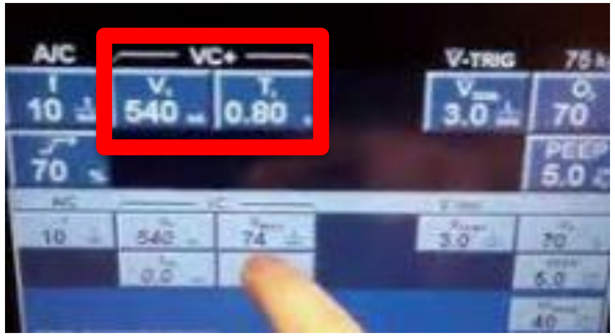
PRVC

Pressure-regulated Volume control

Servol

VC+

Volume control plus



PB840

G5 Hamilton

Examples of proprietary names for the 5 basic modes and 2 feedback features					
	PB840	Avea/Vela	Servo I	G5	Evita V500
VACV	A/C (VC)	VAC	VC	(S) CMV	VC-AC
PACV	A/C (PC)	PAC	PC	P-CMV	PC-AC
VSIMV	SIMV (VC)	VSIMV	SIMV (VC)	SIMV	VC-SIMV
PSIMV	SIMV (PC)	PSIMV	SIMV (PC)	P-SIMV	PC-SIMV
PSV	SPONT (PS)	CPAP/PSV	PS/CPAP	SPONT	PC-PSV
PRVC	VC+	PRVC	PRVC	APV	VC-AC (Autoflow) PC-AC (VG)
APRV	BiLevel	BiPhasic	Bi-Vent	APRV	PC-APRV

- 下列有關PRVC (pressure-regulated volume control) 描述何者為”非”

  A. Dual control, 偏向volume control

  B. 基本上是一種 pressure control, 所以要好好設定pressure

  C. Volume control 基礎下，設定volume 與 Ti

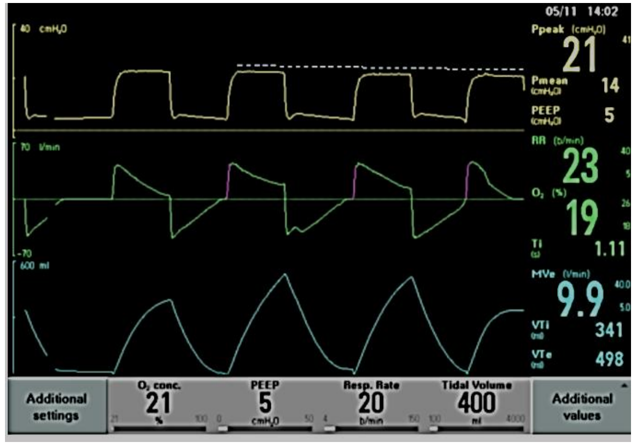
  D. 優點在於讓呼吸器以最低pressure 下於設定時間(Ti)打入設定之體積 (volume)

如下圖，何種通氣模式會允許由呼吸器逐步調整吸氣之壓力？

Pressure

Flow

Volume



Answer: C

A. Volume-targeted control ventilation)

B. Pressure-targeted control ventilation)

C. Pressure-regulated volume control

D. Pressure support ventilation

- 下列有關 volume control model, pressure control model 延伸的Dual control mode 描述何者為”非”

  A. 需要設定的是volume 與 Ti

  B. 基本上是一種 pressure control, 所以要好好設定pressure

  C. 優點在於讓呼吸器以最低pressure 下於設定時間(Ti)打入設定之體積(volume)

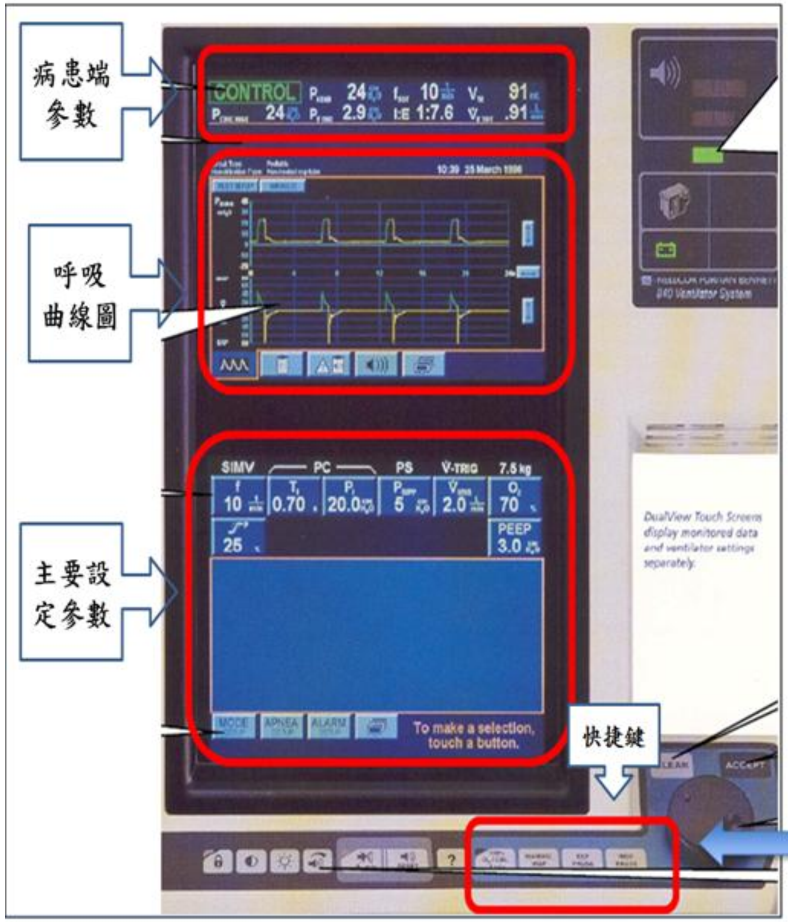
  D.不同呼吸器有不同名稱，如Volume control +、pressure-regulated volume control (PRVC)、CMV-AutoFlow、APVcmv等名稱

Answer: B

呼吸器相關測量

- ✓ Pplat 量測
- ✓ Driving pressure
- ✓ Auto-PEEP
- ✓ Compliance
- ✓ Resistance
- ✓ EtCO2 (capnography)
- ✓ Recruitment

I-hold and E-hold



I-hold for Pplat

(PC/PRVC原則上Pplat就是設定的壓力)

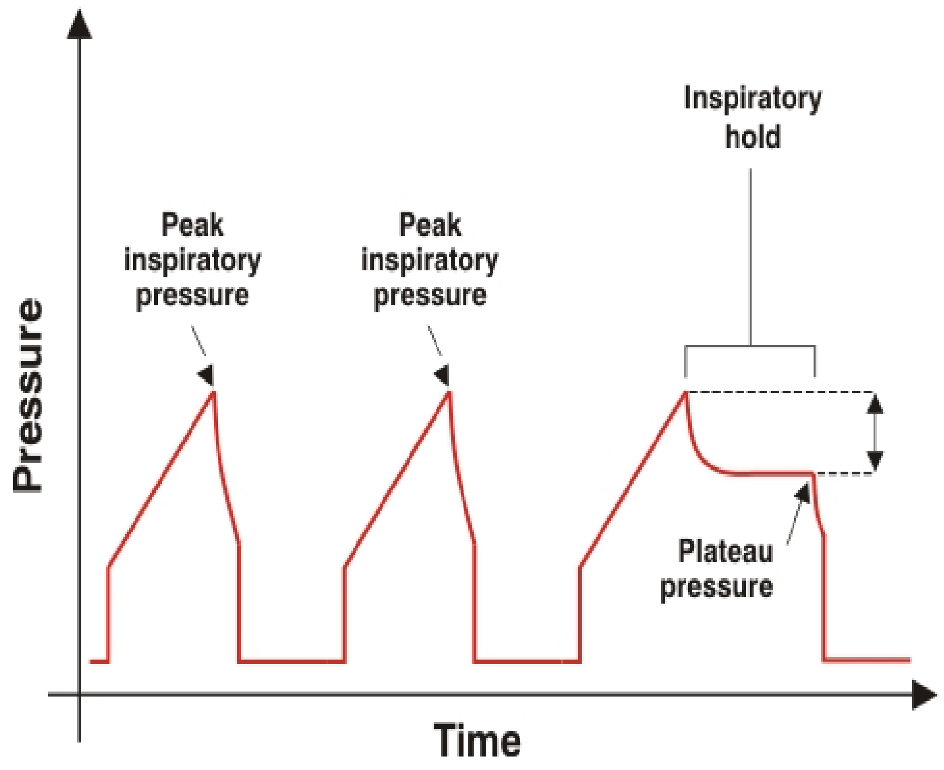
E-hold for true PEEP

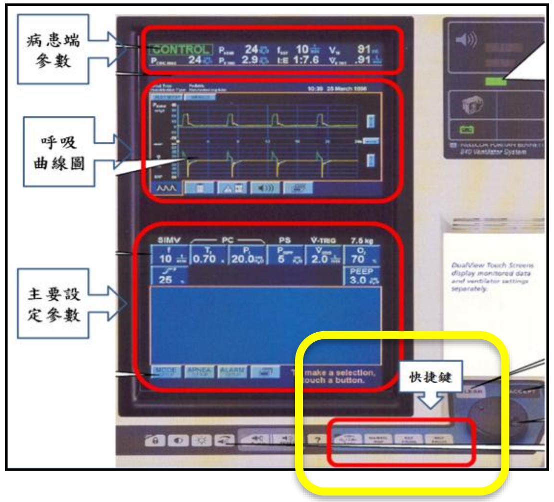
(只是要確認有無auto-PEEP)

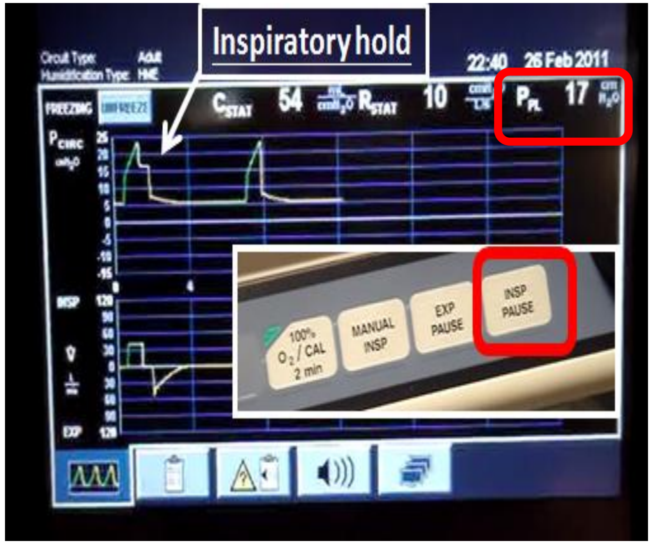
i-hold 看Pplat

e-hold 看auto-PEEP

To measure Pplat: inspiratory-hold





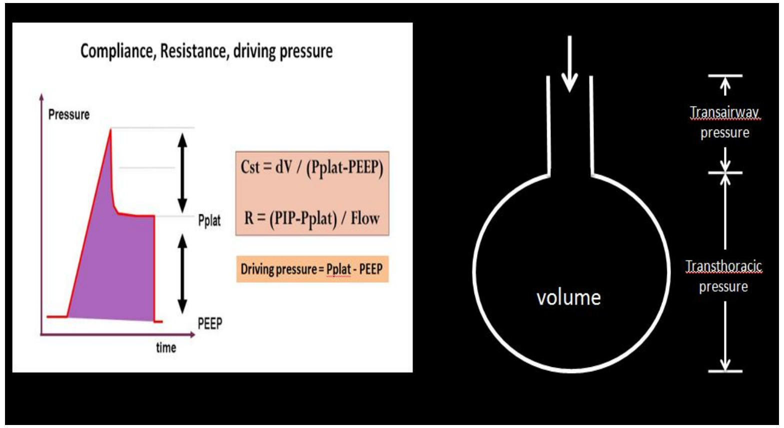


V/C mode, constant flow, Pressure-time curve

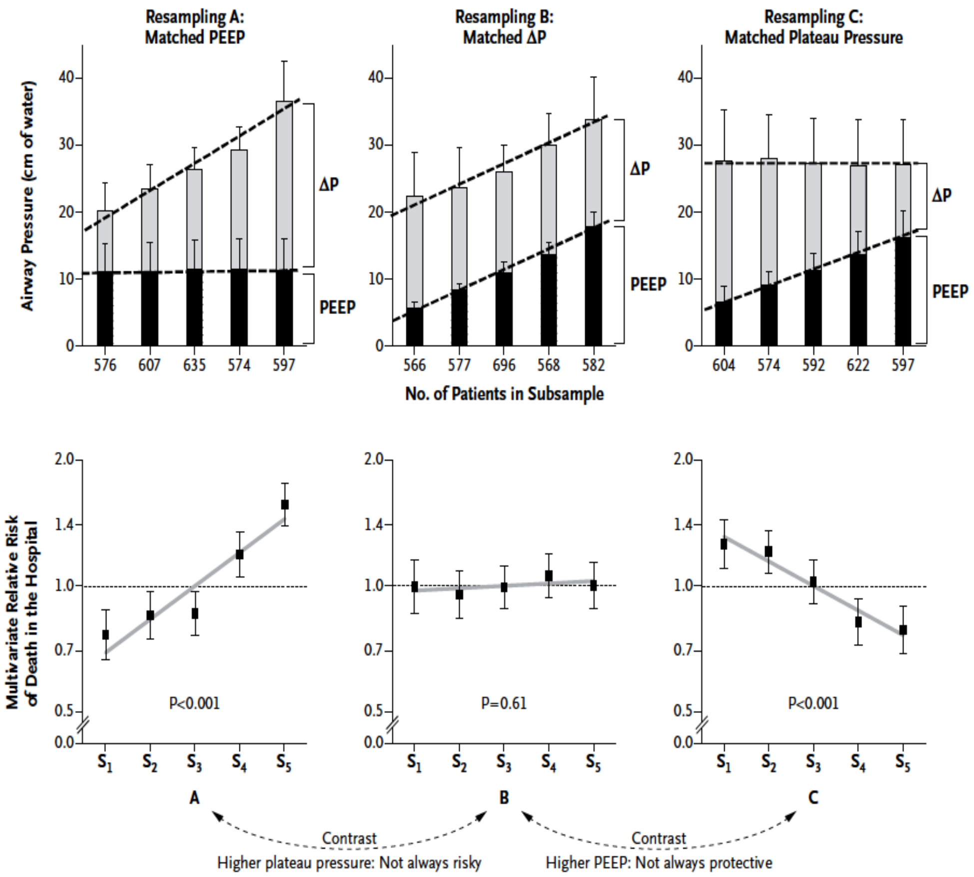
ARDSnet Protocol
Treatment "Goals"

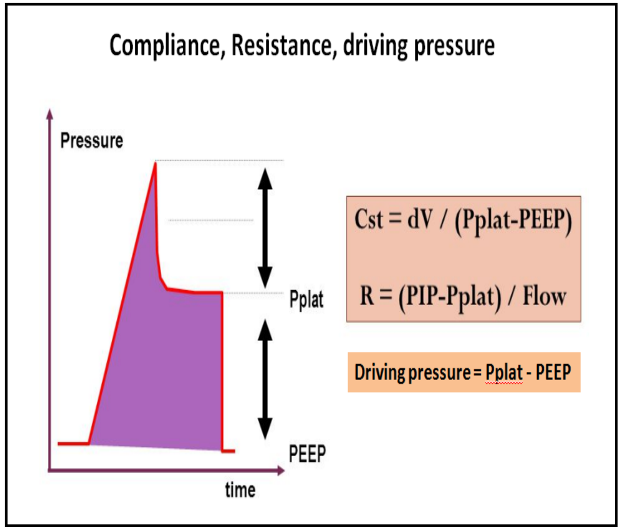
ARDSnet
NIH NHLBI ARDS Clinical Network
Mechanical Ventilation Protocol Summary

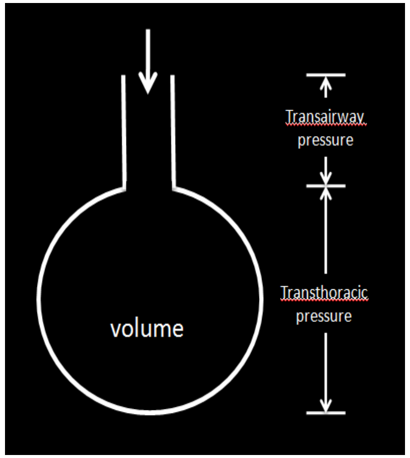
- OXYGENATION GOAL
  - PaO_2 55-80 mmHg or SpO_2 88-95%
- PLATEAU PRESSURE GOAL
  - $\leq 30\ cmH_2O$
- pH GOAL
  - 7.30-7.45
- I: E RATIO GOAL
  - Recommend that duration of inspiration be < duration of expiration.



Driving pressure and survival in the acute respiratory distress syndrome







Amato MB, et al. N Engl J Med. 2015 Feb 19;372(8):747-55

Driving pressure

1.同時考慮吸氣與吐氣的壓力差

2.<14-16 是好事

3.可能是果，不是因

(因為compliance差，所以driving pressure 要大才能打出足夠的tidal volume)

- 有關呼吸器設定 driving pressure 的描述何者為非？

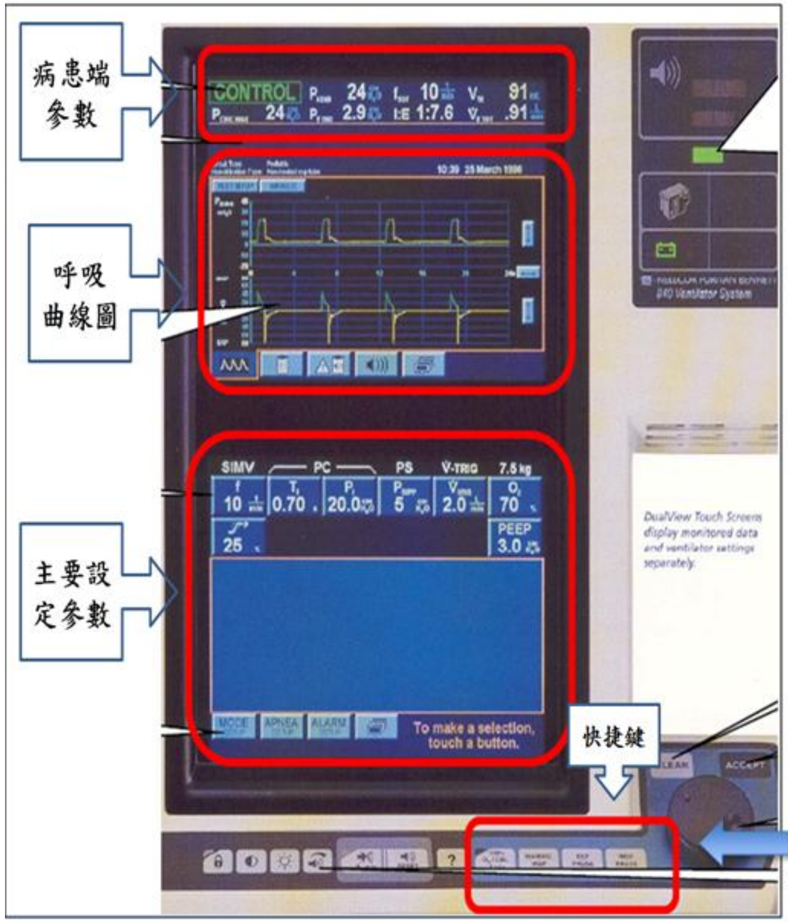
(A) driving pressure 為 plateau pressure 減 PEEP

(B) 相同 driving pressure 下，plateau pressuree 愈高，死亡率愈高。

(C) 相同 driving pressure 下，PEEP 愈高，死亡率不會降低。

(D) driving pressure 大於 15cmH2O，死亡率會上升

I-hold and E-hold



I-hold for Pplat

(PC/PRVC原則上Pplat就是設定的壓力)

E-hold for true PEEP

(只是要確認有無auto-PEEP)

i-hold 看Pplat

e-hold 看auto-PEEP

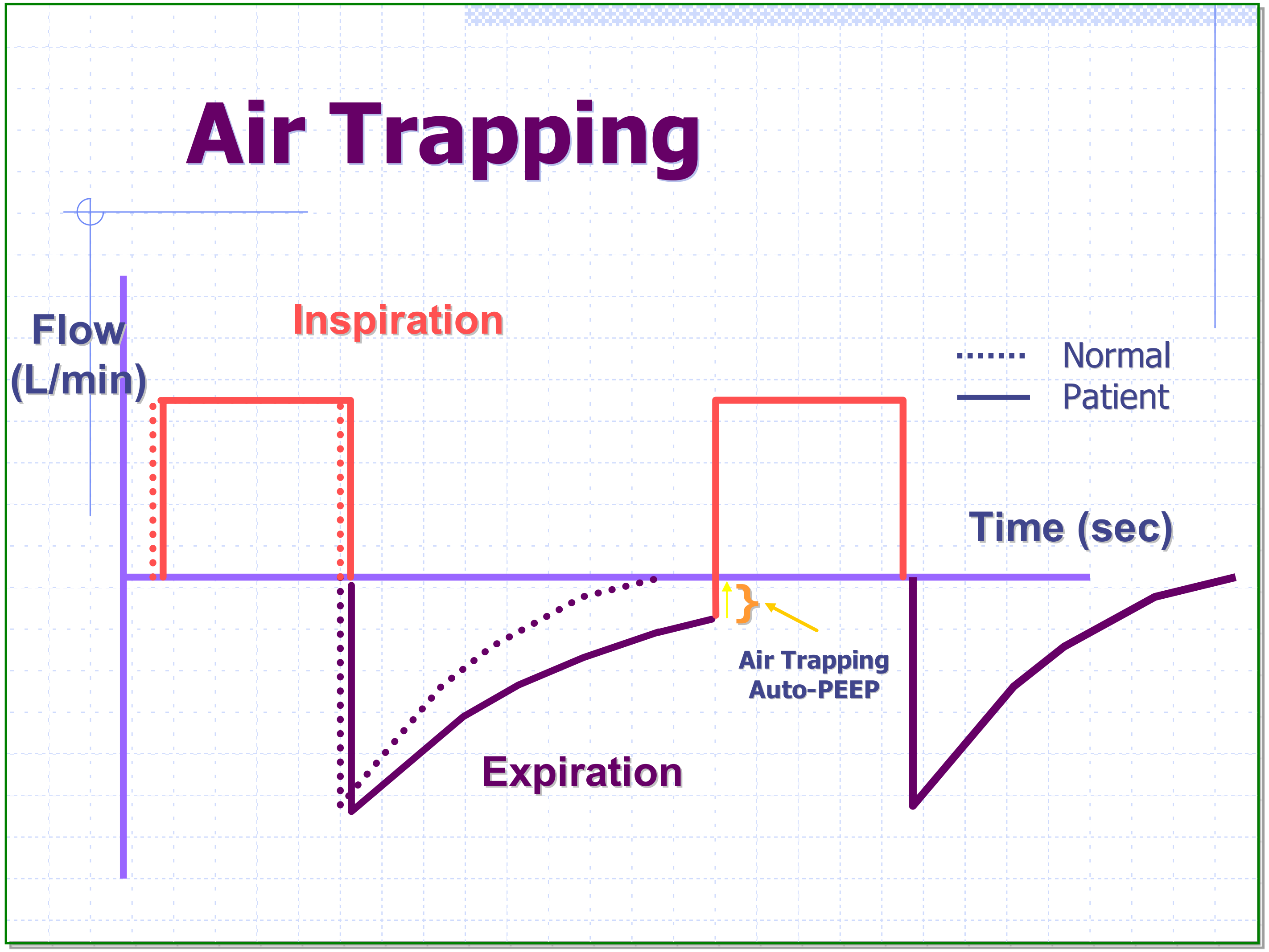
怎麼量出auto-PEEP

e-hold

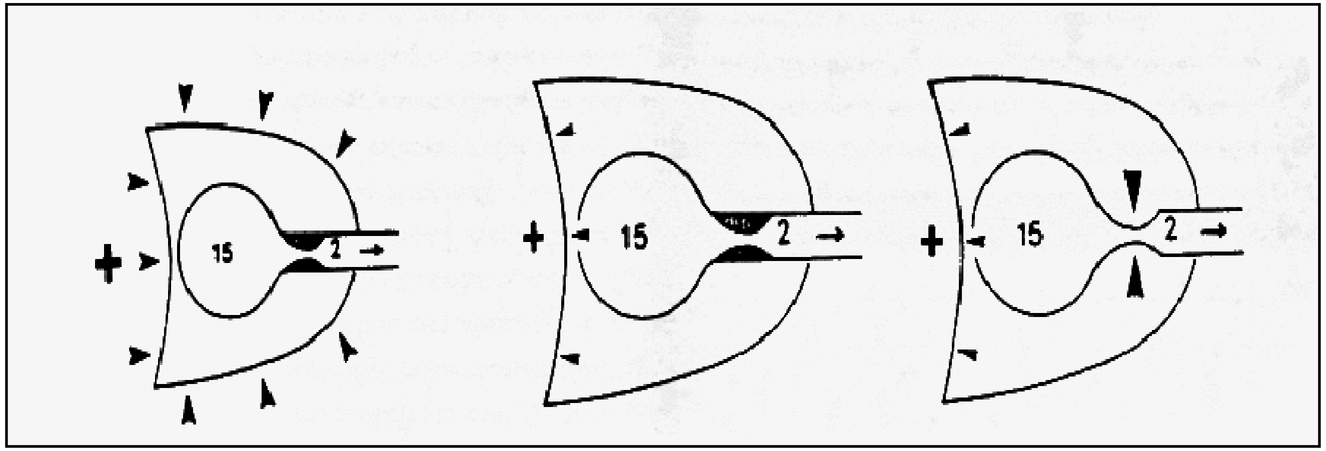
PEEP total: 7.8
PEEP set: 6
Peep intrinsic: ~1.7

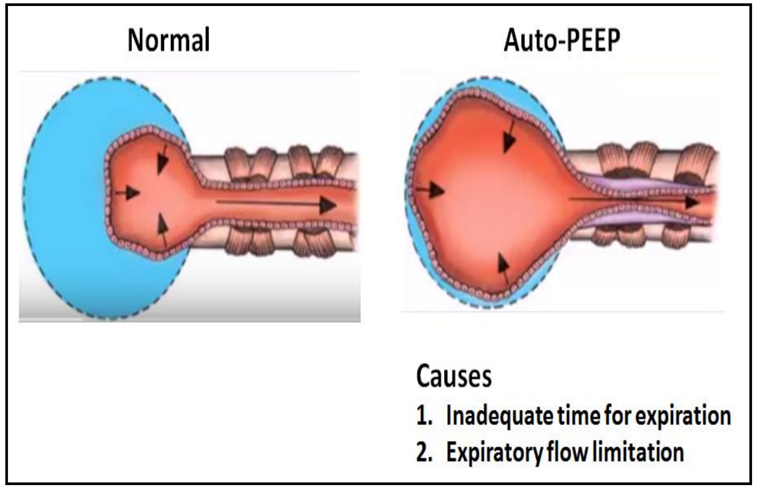
Flow-time：吐氣期 flow 未歸零

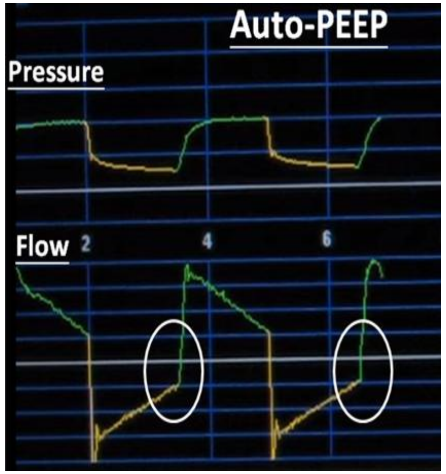
吐氣期還在吐氣，機器就把氣打進來了



Auto-PEEP (Intrinsic PEEP, PEEPi)







★

Clinical management to relieve auto-PEEP

1. 短暫disconnect (10-15 sec) (讓呼吸道或管路累積過高壓力先釋放出)
might be life-saving in some conditions, such as severe asthma attack.

2. 延長吐氣期時間 (讓肺內氣體慢慢呼出)

a. 降低 respiratory rate (必要時上sedation)
b. 增加吸氣(打氣)的 flow (**目的:縮短吸氣期)**
c. 降低tidal volume (須注意ventilation volume 是否足夠-> f/u $PaCO_2$)

3. 降低呼吸道阻力 (治療bronchospasm)

a. bronchodilators b. steroid c. antibiotics to control airway infection

4. 降低ventilation demand

a. to reduce dead space ventilation/anxiety/pain/fever/asynchronization-> anxiolytic+sedation
b. to reduce carbohydrate intake -> high-fat diet

5. 使用external-PEEP 克服 intrinsic PEEP

mostly applied in COPD. Applied PEEP ~ 80% of auto-PEEP

- 加護病房中，常見呼吸器的使用於心肺衰竭的病人身上，有關吐氣末正壓(positive end expiratory pressure, PEEP)的設定及對血行動力學的影響，下列敘述何者錯誤？

(A) 對於血管內水分不足的病人，PEEP 會使血壓下降

(B) 對於重度心衰竭的病人，PEEP 會改善肺水腫

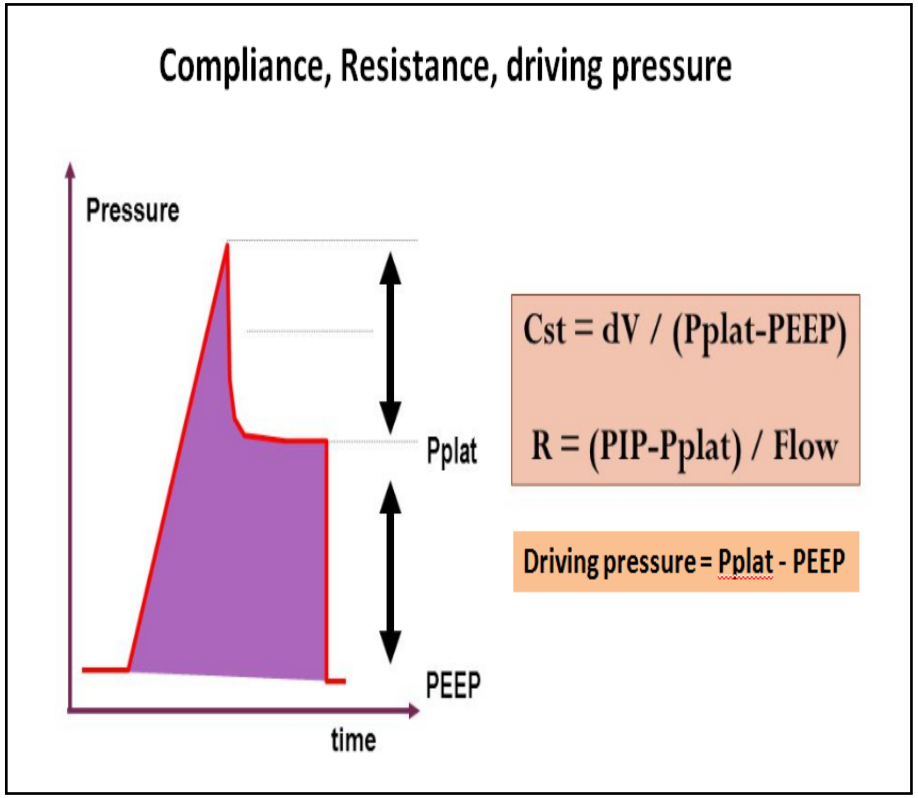
(C) 對於慢性阻塞性肺病急性發作、引起呼吸衰竭的病患，不應使用PEEP，以免加重吐氣困難

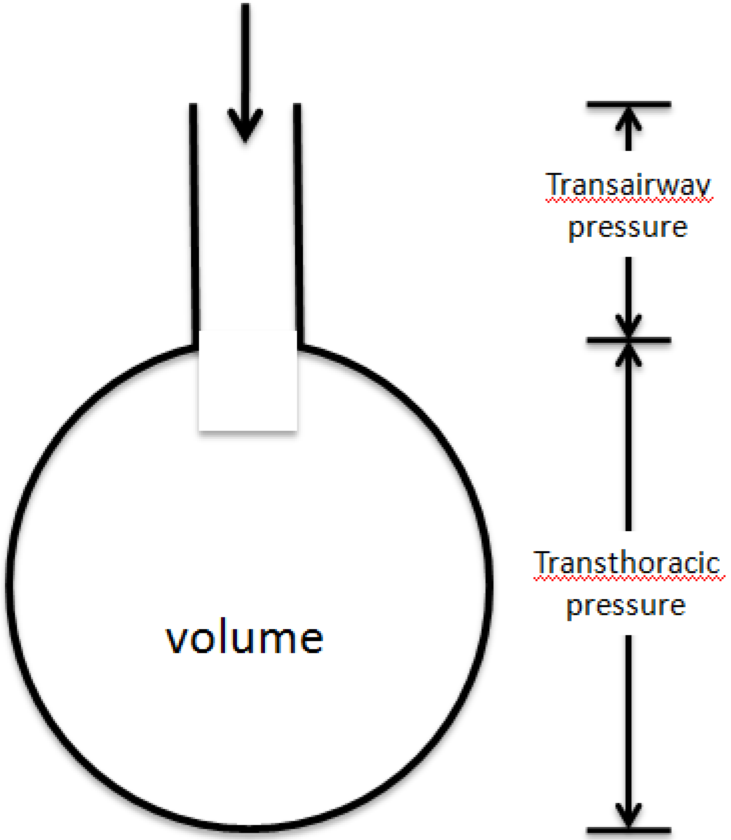
(D) 對於急性呼吸窘迫症候群(ARDS)病患，應使用高PEEP，避免肺泡塌陷

Pressure-time

Resistance and compliance

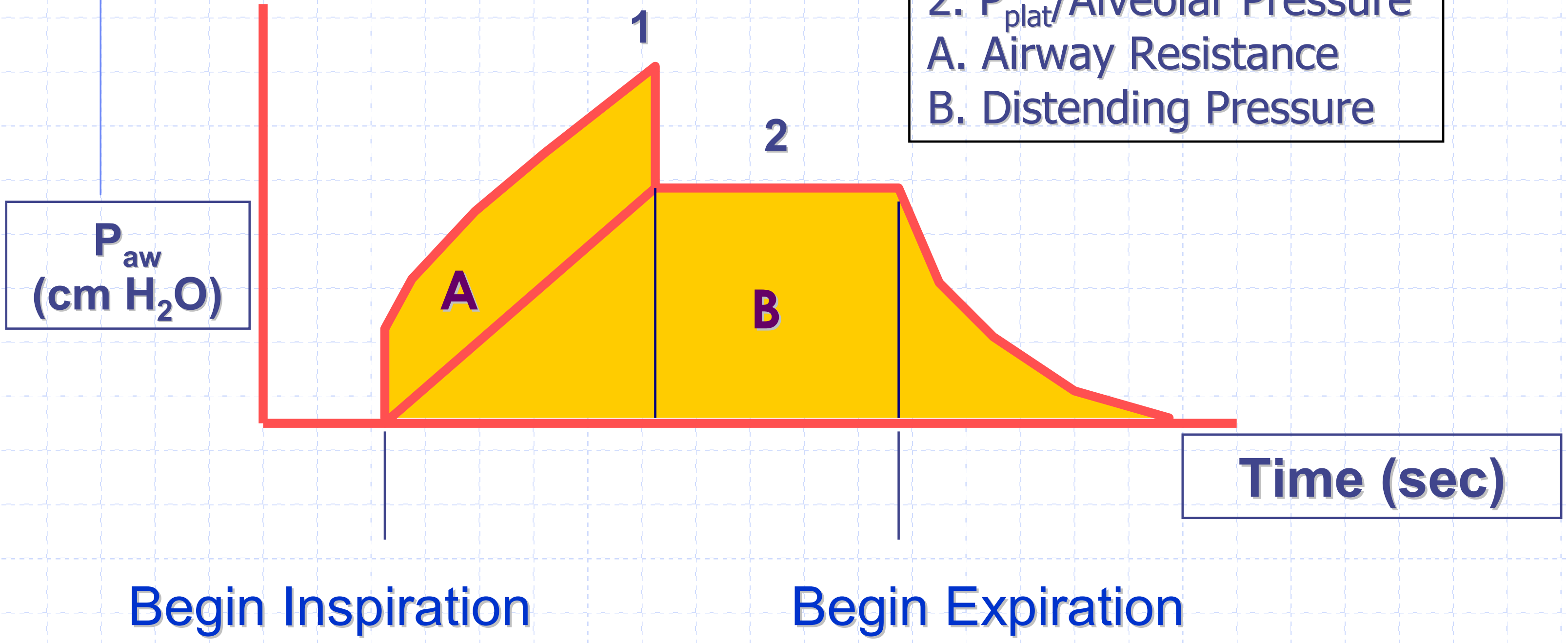
Compliance, resistance, and driving pressure





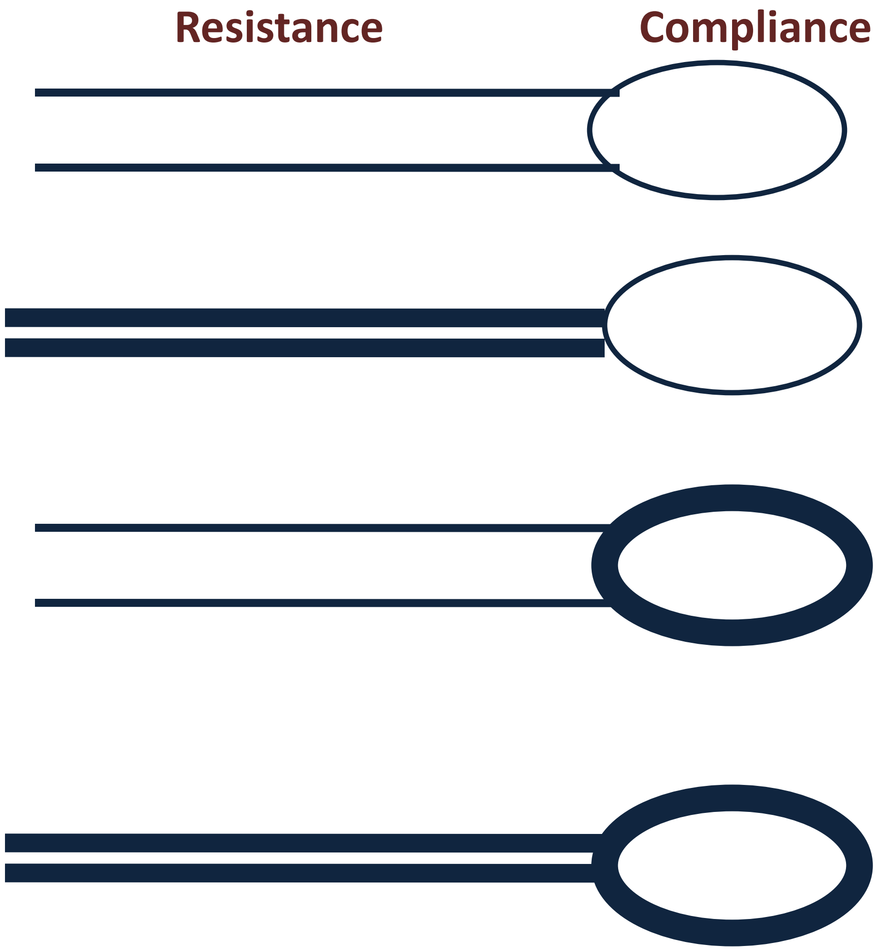
肺生理教科書➔但要VC model且constant flow才會出現

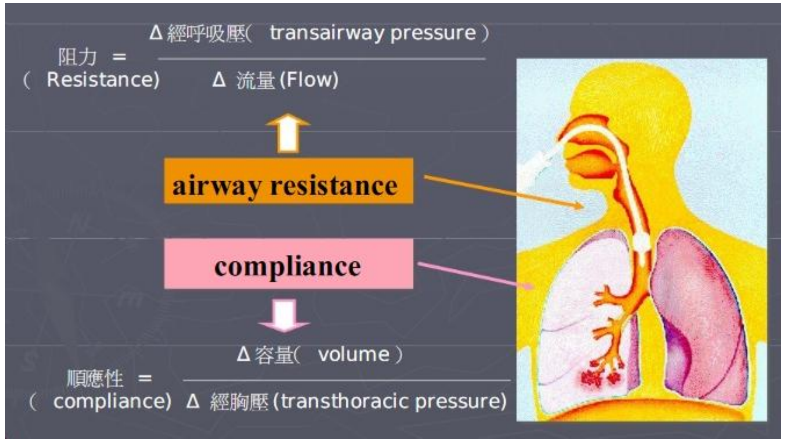
Components of Inflation Pressure

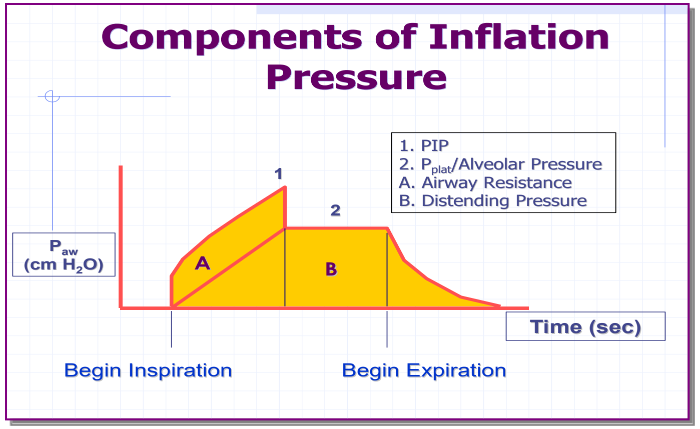


1. PIP
2. P_{plat}/Alveolar Pressure
A. Airway Resistance
B. Distending Pressure

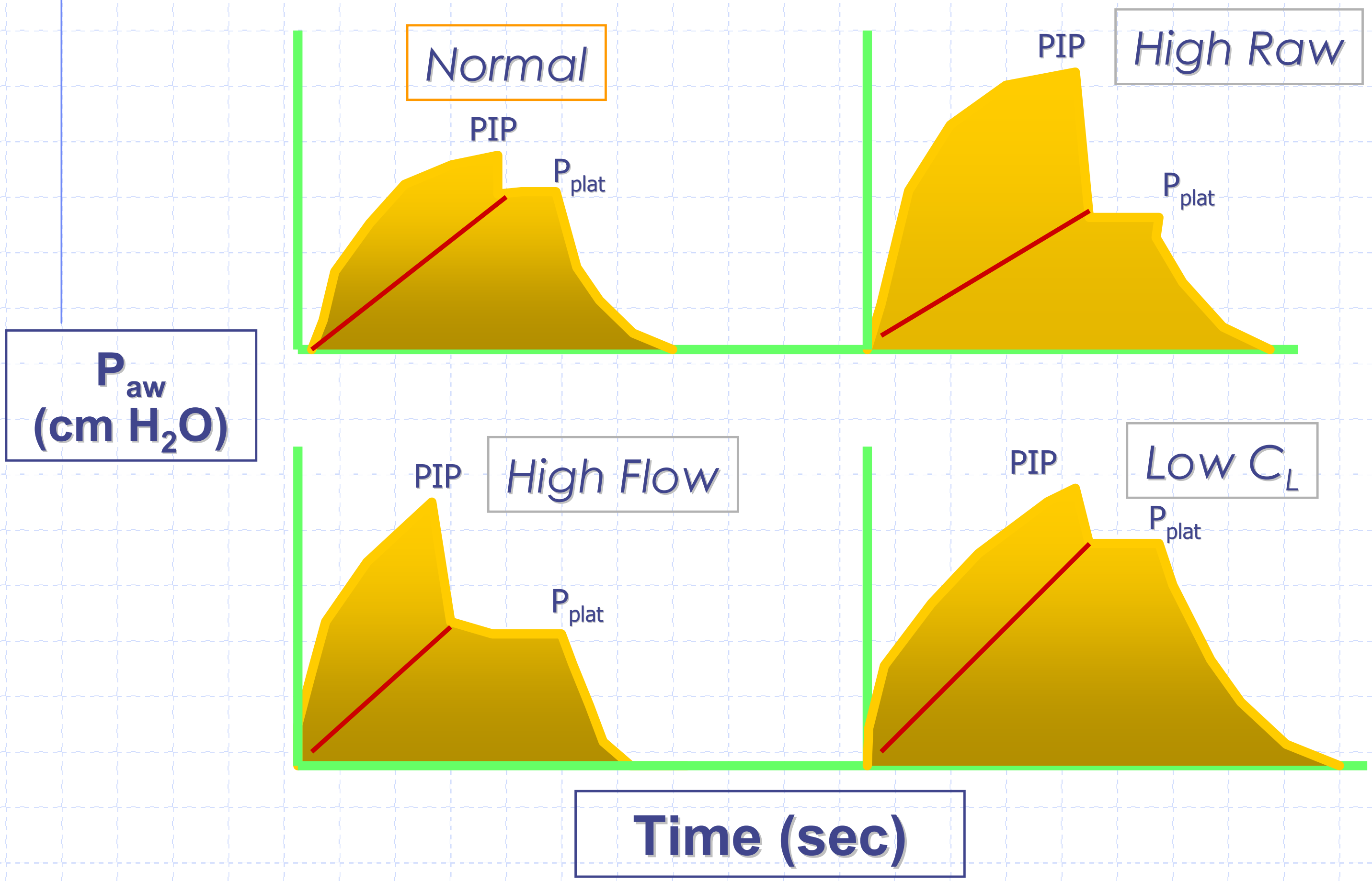
Resistance and compliance







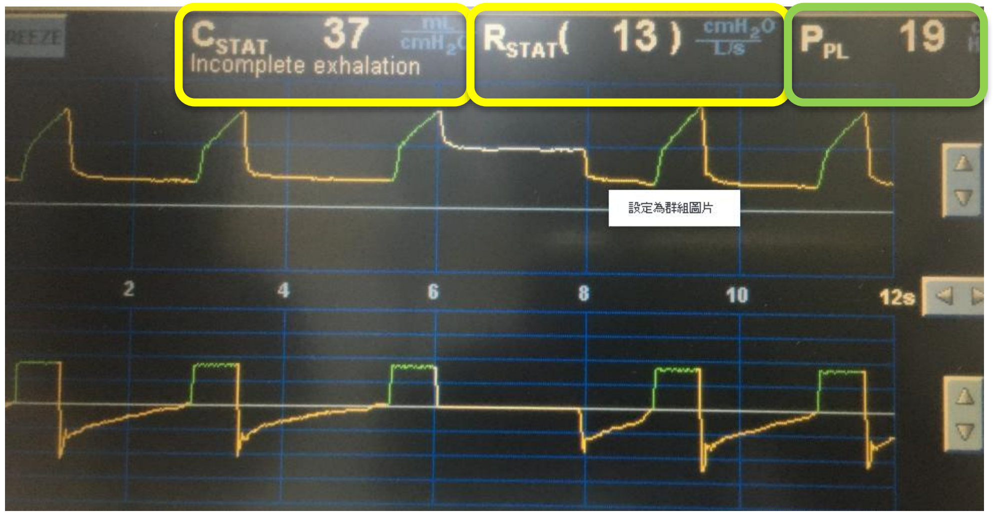
PIP vs P_{plat}



P_{aw} (cm H_2O)
Normal
PIP
P_{plat}
High Raw
PIP
P_{plat}
High Flow
PIP
P_{plat}
Low C_L
PIP
P_{plat}
Time (sec)

Airway problem (resistance)

怎麼量出 Compliance + Resistance



1. 調Volume control
2. 改constant flow
3. I-hold

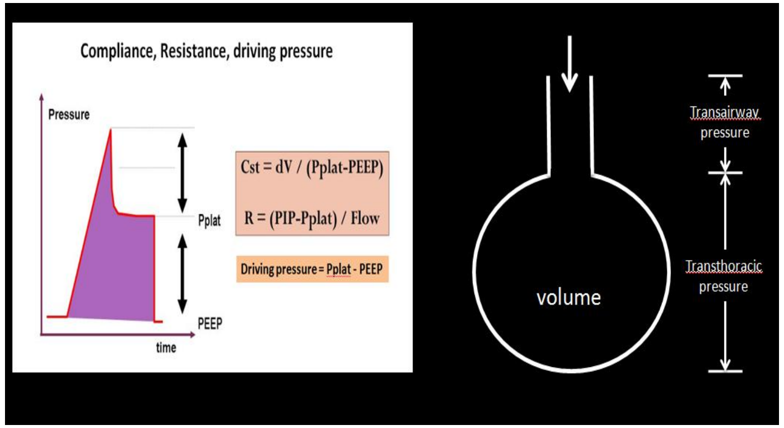
➔Cstat= △Volume /△Pressure

(Tidal volume / P_{pl}-P_{PEEP})

ARDSnet Protocol
Treatment "Goals"

NIH NHLBI ARDS Clinical Network
Mechanical Ventilation Protocol Summary

- OXYGENATION GOAL
  - PaO_2 55-80 mmHg or SpO_2 88-95%
- PLATEAU PRESSURE GOAL
  - ≤ 30 cmH_2O
- pH GOAL
  - 7.30-7.45
- I: E RATIO GOAL
  - Recommend that duration of inspiration be < duration of expiration.



Capnography

etCO2: end-tidal CO2

- PaCO2 和 etCO2 約有20的落差➔PaCO2 = etCO2 + 20
  [因為CO2 sensor接近進氣端，所以吐氣端的CO2會被沖淡一點]

- 急性呼吸窘迫症候群(ARDS)病人，呼吸器設定使用吐氣末陽壓(PEEP)治療何者錯誤？

(A) 提供適當的氧合，降低 FiO_2

(B) 防止肺泡塌陷，提供適當的組織氧合

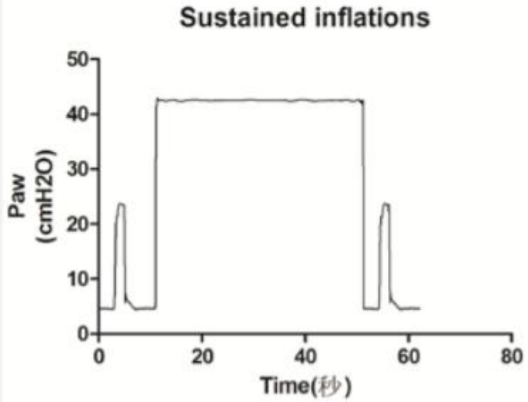
(C) 增加肺部之功能肺餘量(FRC)

(D) 降低肺部之順應性(compliance)

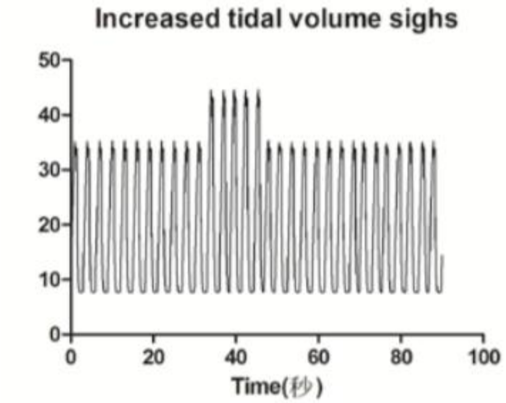
Recruitment

40 cmH_2O for 40 sec

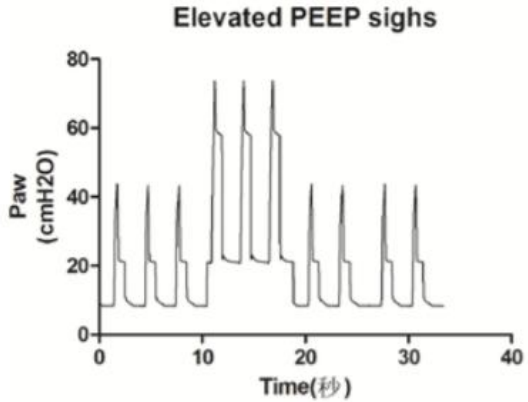
Recruitment methods



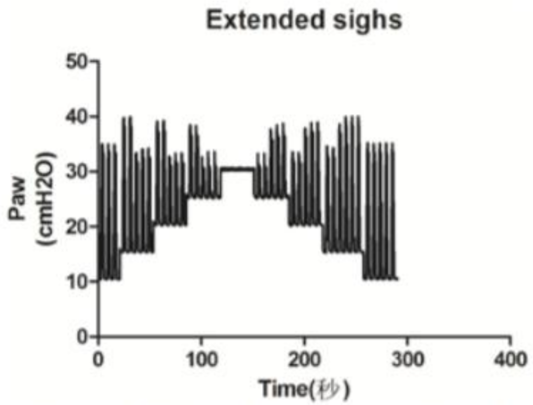
圖一：持續性肺膨脹術示意圖。本圖作法是以持續性正壓40 cmH_2O維持40秒。



圖二：深呼吸的一種(示意圖)：在一段呼吸間給予較高的潮氣容積(以高原壓力45 cmH_2O為上限之容積模式)。



圖三：深呼吸的另一種模式(示意圖)：在一段呼吸間給予較高吐氣末正壓(一般給予3次/每分鐘)。

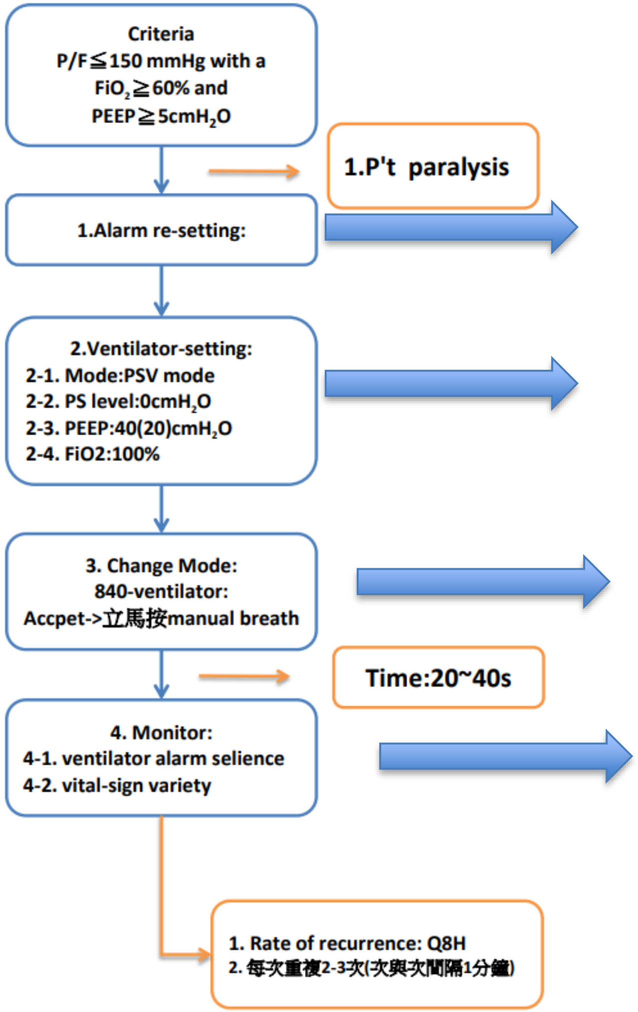


圖四：深呼吸的一種(延長式深呼吸)(示意圖)：結合深呼吸及持續性肺膨脹，逐漸增加吐氣末正壓及逐漸遞減潮氣容積，直到最後形成持續性肺膨脹(持續性正壓30 cmH_2O維持30秒)，之後再逐漸減少吐氣末正壓及逐漸遞增潮氣容積。

鄭人碩, 內科學誌 2013:24;86-93

Recruitment in PB840

(40 cmH2O for 40 sec)



I. High pressure alarm 拉高50以上

II. Back up 拉高至60 秒

PS mode, FiO2 100%, PS 0, PEEP 40

Accept + Manu breath

Back to previous mod

🔵 Revisited

肺擴張復甦手法（Recruitment Maneuver）

Recruitment Maneuvers in Sepsis-Associated Moderate-Severe ARDS

❌ 反對常規使用 Recruitment Maneuver

2026 年更新：對於敗血症合併中重度 ARDS，建議反對常規使用 Recruitment Maneuver。

Conditional recommendation against | Moderate certainty

⚠️ 重大變化（vs 2021）

2021 指引：條件性建議可使用傳統 Recruitment Maneuver（weak, moderate evidence）。

2026 指引：改為條件性建議反對常規使用，為本章節最重要變化之一。

📋 主要依據

循證更新：ART Trial（2017）顯示遞增PEEP型Recruitment Maneuver顯著增加28天死亡率（RR 1.20）；後續系統性回顧亦未能確認傳統RM之臨床獲益，反見不良事件風險。

若仍需考慮使用，應避免以下方式：

- Staircase（遞增PEEP）型 RM — 強烈反對（Carryover）
- 高氣道壓長時間持續充氣型 RM — 強烈反對

🔑 2026 核心改變：從「可考慮」轉為「不建議常規使用」，反映更多高品質試驗的負面結果。

Revisited — 不建議 incremental PEEP

建議：反對使用遞增式 PEEP 滴定策略

Recommend Against Incremental PEEP Titration

建議聲明（Strong Recommendation，Moderate Certainty）對於敗血症合併中重度 ARDS 的成人，強烈建議反對使用遞增式 PEEP 滴定策略（incremental PEEP titration / staircase recruitment maneuver）。

For adults with sepsis and moderate-severe ARDS, we "recommend against" using an incremental PEEP titration strategy.

與 2021 比較

2021 版在「建議使用傳統 Recruitment Maneuver」的前提下，附加建議反對 incremental PEEP。2026 版更新措辭與臨床情境，維持強烈反對立場。

主要危害與依據

ART 試驗（2017）

遞增式 PEEP 肺復張策略組（最高 PEEP 達 45 cmH_2O）較對照組有更高的 28 天死亡率（55.3% vs. 49.3%）

血流動力學危害

高 PEEP 遞增過程中可引起顯著低血壓、心輸出量下降及右心室功能障礙，增加血流動力學不穩定風險

氣壓傷風險

過高的氣道壓力增加氣胸、縱膈氣腫等氣壓傷發生率

New — 缺氧監測

建議：缺氧監測方式
Hypoxemia Monitoring

建議聲明（Conditional Recommendation，Very Low Certainty）對於敗血症成人患者，建議使用脈搏血氧計（SpO_2）或動脈血氧飽和度（SaO_2）搭配身體評估及臨床判斷，來監測缺氧狀態。

For adults with sepsis, we "suggest" measuring oxygenation by either pulse oximeter (SpO_2) or arterial blood gas (SaO_2) in conjunction with physical examination and clinical acumen.

SpO_2/FiO_2 的侷限性

在休克、皮膚色素較深、SpO_2 <90% 或 >97% 的患者中，SpO_2/FiO_2 替代 PaO_2/FiO_2 的準確性下降，需謹慎判讀。

ABG 仍是黃金標準

動脈血氣分析提供 pH、$PaCO_2$、乳酸、重碳酸鹽等額外重要資訊，條件允許時優先使用。

PaO_2/FiO_2 <300 mmHg 或 SpO_2/FiO_2 <315

PaO_2/FiO_2 <200 mmHg 或 SpO_2/FiO_2 <235

為何是 New 建議？

2021 指引未針對缺氧監測方式提出明確建議。2026 版首次將監測工具本身納入建議範疇，強調臨床判斷不可被單一數值取代。

SpO_2 by Pulse Oximeter

非侵入性、連續監測、資源有限環境可行

SaO_2 by ABG

更精準、含更多代謝資訊、為黃金標準

臨床要點：「In our practice」— 小組成員在敗血症合併急性缺氧性呼吸衰竭患者中，SpO_2 目標介於 90%（IQR 90–92%）至 96%（IQR 94–98%）之間。

Revisited — 氧氣目標

建議二：氧氣目標設定Oxygen Targets / FiO_2 Titration

對於敗血症合併急性缺氧性呼吸衰竭的成人，建議根據患者情況及資源限制，將 FiO_2 滴定至較高（自由）或較低（保守）的氧氣目標。

1

2021 建議（No Recommendation）

2021 版「證據不足」，無法對保守性氧氣目標提出建議

2

2026 更新（Conditional Recommendation）

2026 版基於新證據，發出條件性建議，允許彈性滴定

Certainty of Evidence: Low雖然各試驗間有差異性，但多數研究採用的下限目標約為 SpO_2 90–93%，**上限目標為 SpO_2 ≥96%。**

ESG (Environmental+Social+Governance) at TCVGH

➔SaO2 >96%, 請評估調整FiO2

主要證據依據

HOT-ICU 試驗

急性缺氧性呼吸衰竭 ICU 患者中，保守與較高氧氣目標在 90 天死亡率上無顯著差異

PILOT 試驗

機械通氣患者中，不同 SpO_2 目標（低/中/高）在 ventilator-free days 上無顯著差異

高氧的潛在危害

自由用氧策略（SpO_2 中位數 96%）與住院死亡率增加相關（RR 1.21），避免 SpO_2 持續 >96%

實務建議：SpO_2 目標 90–96%，避免過度用氧；資源有限環境下保守目標同樣可行。

呼吸器相關測量

- ✓ Pplat
- ✓ Driving pressure
- ✓ Auto-PEEP
- ✓ Compliance
- ✓ Resistance
- ✓ EtCO2 (capnography)
- ✓ Recruitment
- ✓ Optimal oxygnenation

Outline

- **呼吸器三大基本要素: trigger, limit, cycle**
- **呼吸器相關測量**

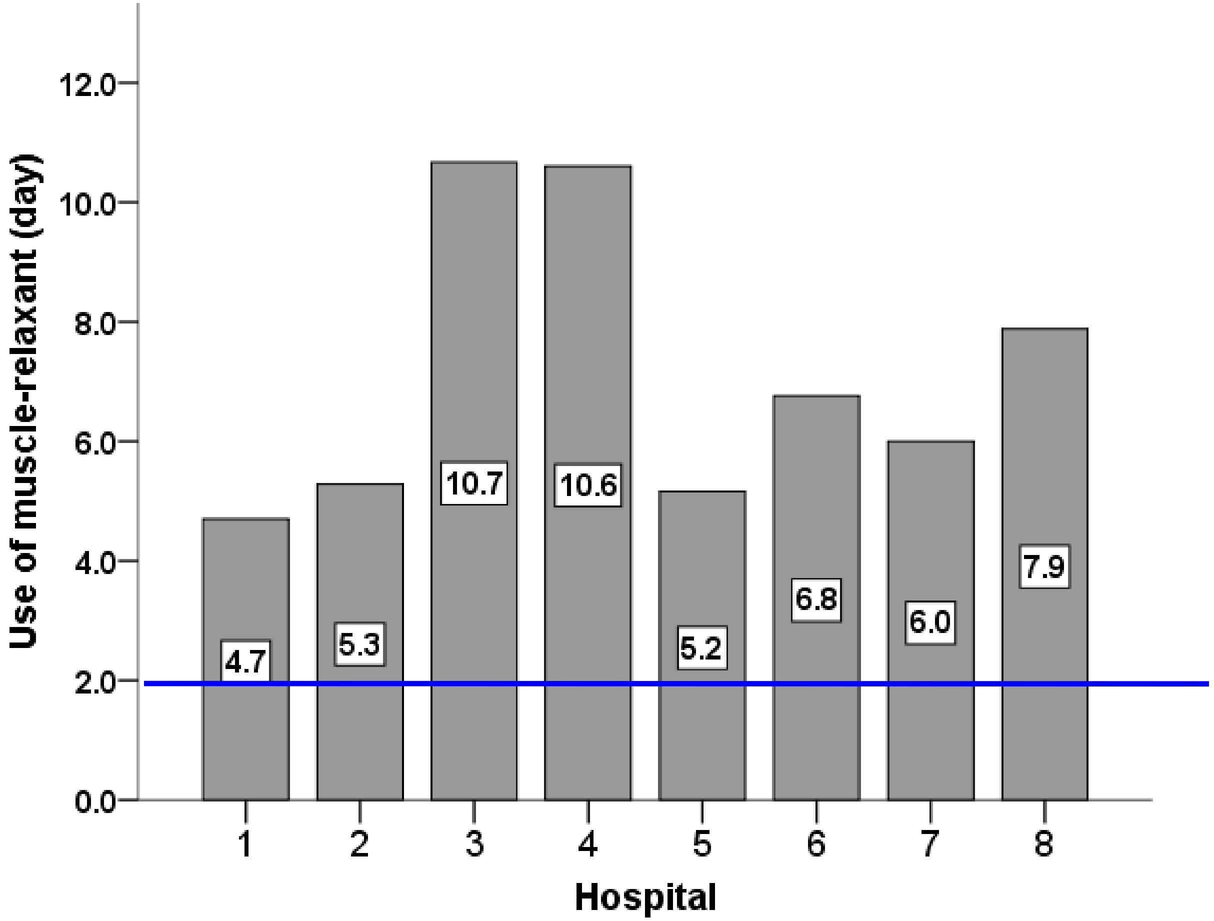
  Pplat 量測, driving pressure, resistance, compliance,

  autoPEEP, capnography, breath stacking, recruitment
- **Neuromuscular blockade (NMBA) usage and Patient Self-Inflicted Lung Injury (P-SILI)**

Taiwan Severe Influenza Research Consortium (TSIRC)

2016/03/12

Administered-day of NMBA in subjects with influenza-related severe ARDS by participating hospital



Taiwan Severe Influenza Research Consortium (TSIRC) investigators.

Optimal use of NMBA in ARDS: the role of spontaneous breathing

Fifty Years of Research in ARDS. **Spontaneous Breathing** During Mechanical Ventilation - Risks, Mechanisms & Management.

Yoshida T et al. Am J Respir Crit Care Med. 2016 Oct 27

Spontaneous breathing in ARDS

NO

Esophageal pressure swings during spontaneous breathing in normal conditions and with ARDS

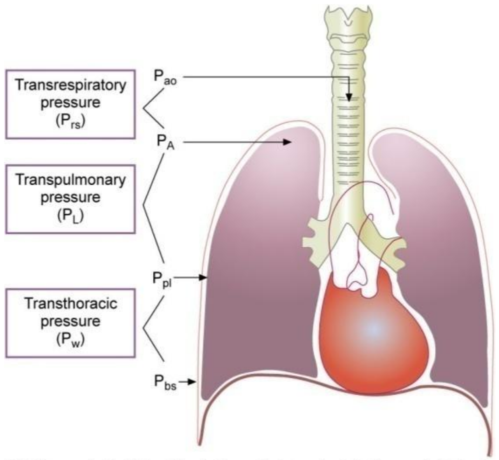


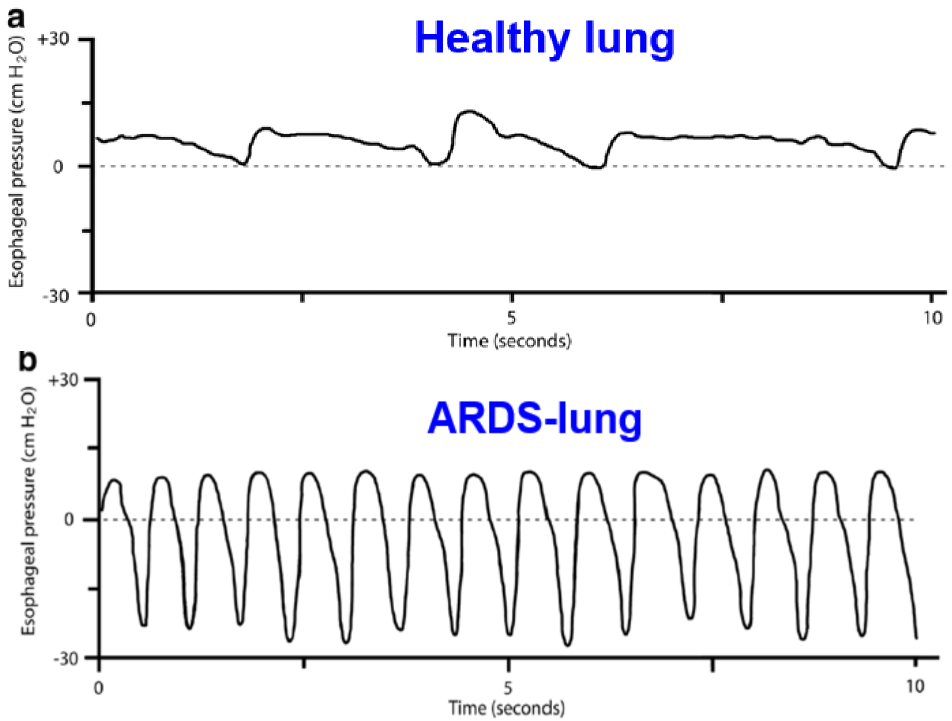
Fig. 3-2. Pressure gradients involved in ventilation. P_{ao}, Pressure at the airway opening; P_A, alveolar pressure; P_{pl}, intrapleural pressure; P_{bs}, pressure at the body surface; P_{rs}, transrespiratory pressure; P_L, transpulmonary pressure; P_W, transthoracic pressure. P_{rs} is equal to either ($P_{ao} - P_A$) or ($P_{bs} - P_A$) in a spontaneously breathing individual and can be thought of as the pressure gradient between the mouth and alveoli or the transairway pressure.

$$P_L = P_A - P_{pl}$$

(P_L: trans-pulmonary pressure)

Esophageal pressure

Esophageal pressure

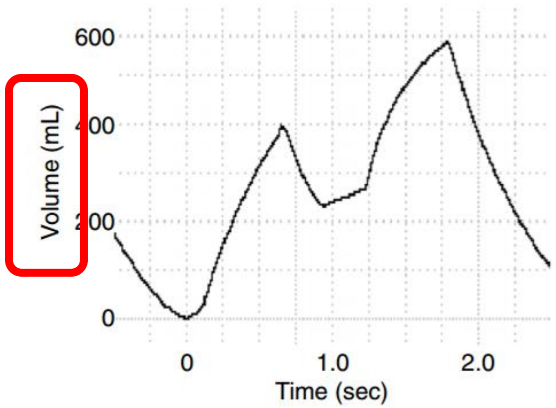


Oleic acid-induced ARDS sheep model

Langer T. Santini A, Bottino N, Crotti S, Batchinsky AI, Pesenti A, Gattinoni L.
Crit Care. 2016 Jun 30;20(1):150.

Quantifying unintended exposure to high tidal volumes from breath stacking dysynchrony in ARDS: the BREATHE criteria

NMBA reduced the breath stacking from 23/hr to 0/hr



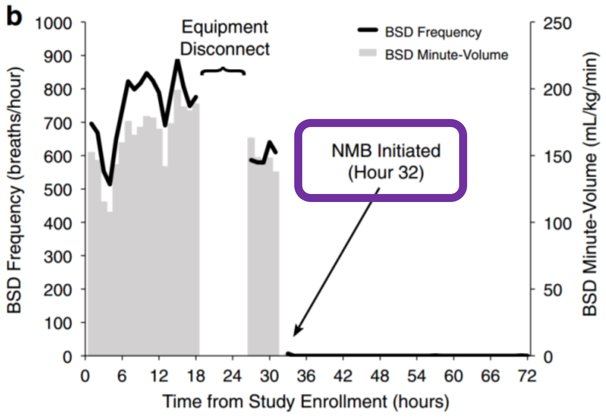


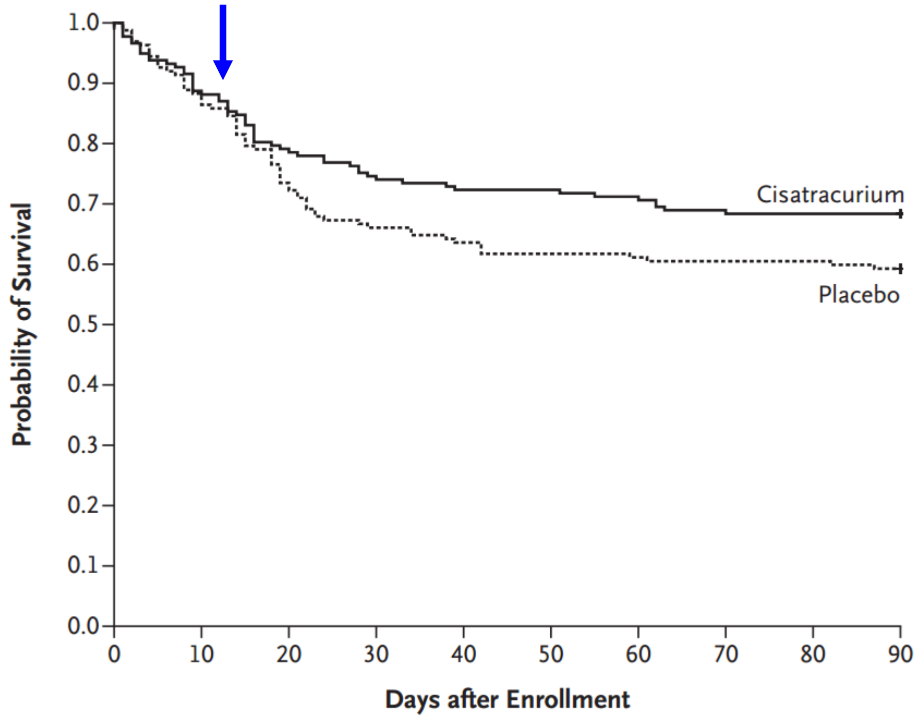
Table 4 Breath stacking dyssynchrony applying BREATHE criteria among recipients of neuromuscular blockade

Stacked breath characteristic	During paralysis	Absent paralysis	*p* value
No. breaths analyzed	42,860 ± 24,057	46,677 ± 31,697	0.811
No. stacked breaths	5 (2–15)	576 (53–1332)	0.004
No. stacked per hour	0 (0–1)	23 (7–31)	0.004
Set V_T of stacked breaths (mL/kg PBW)	6.0 (5.8–6.3)	6.3 (6.0–6.8)	0.125
BSD V_T (mL/kg PBW)	11.8 (11.1–14.1)	11.5 (10.5–13.3)	0.461

Beitler, JR et al.
Intensive Care Med (2016) 42: 1427..

Neuromuscular blockers in early acute respiratory distress syndrome

ACURASYS



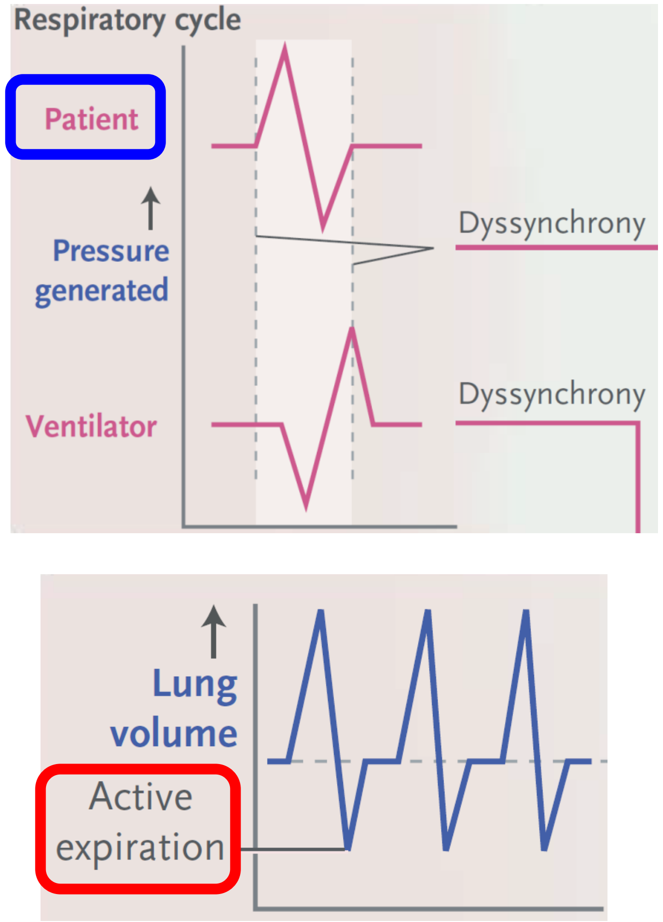
- **2 days of Cisatracurium**
- **Patients with severe ARDS. (P/F ratio < 150)**
- The impact of **VILI** appeared to be prominent after day-15

(Baseline mortality: 45%)

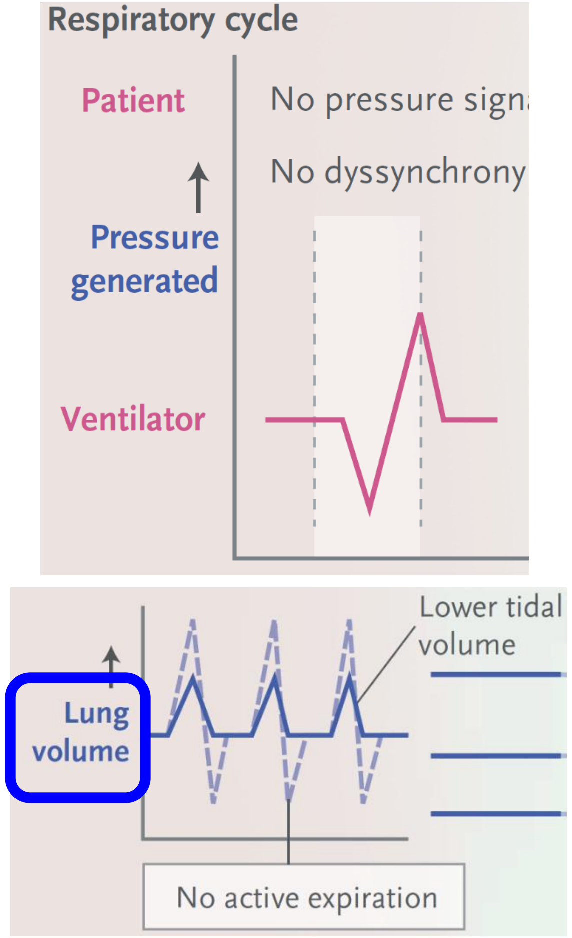
Papazian L. et al. ACURASYS Study Investigators. N Engl J Med. 2010 Sep 16;363(12):1107-16.

Neuromuscular blocking agents in ARDS

Before paralysis



After paralysis



Slutsky AS.
N Engl J Med. 2010 Sep 16;363(12):1176-80.

Mechanical Ventilation to Minimize Progression of Lung Injury in Acute Respiratory Failure

Patient **S**elf-**I**nflicted **L**ung **I**njury

- **High respiratory drive**
- **High Pes swings**
- **Pendelluft**

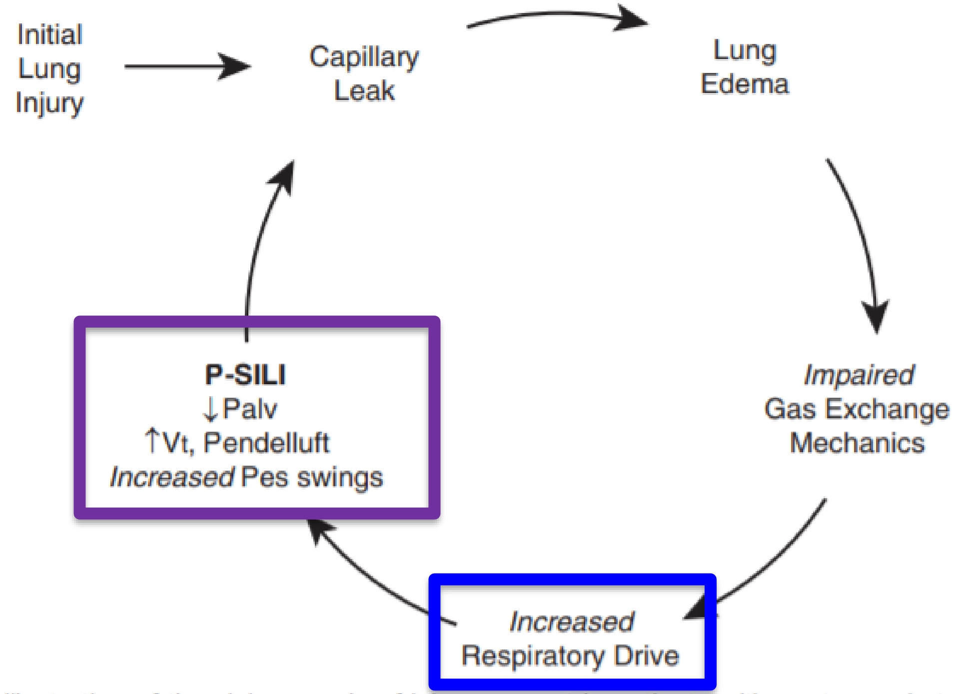


Figure 2. Illustration of the vicious cycle of injury present in patients with acute respiratory failure. Palv = alveolar pressure; Pes = esophageal pressure swings; P-SILI = patient self-inflicted lung injury.

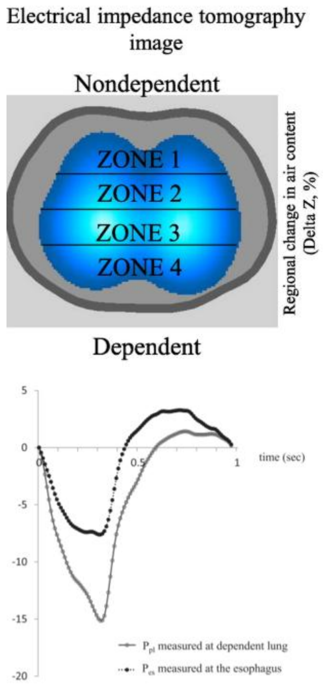
Laurent Brochard

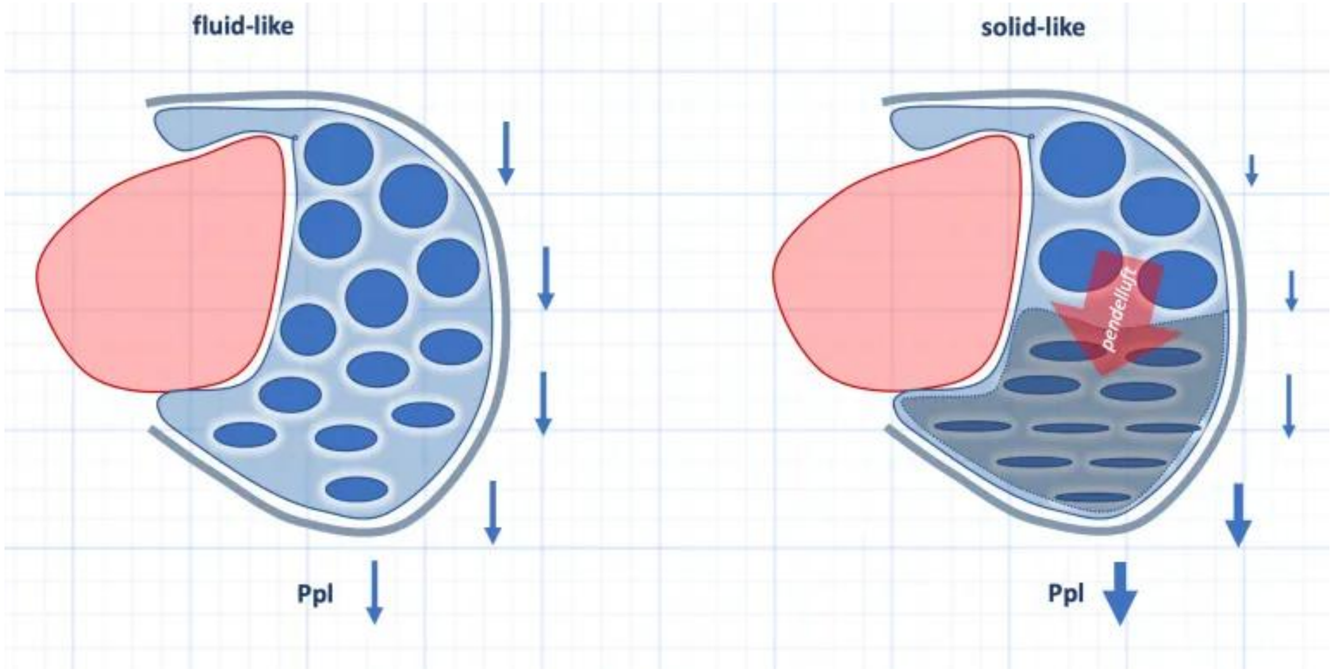
Paris University

Laurent Brochard, Arthur Slutsky, Antonio Pesenti

Am J Respir Crit Care Med . 2017 Feb 15;195(4):438-442. PMID: 27626833

Spontaneous effort causes occult pendelluft during mechanical ventilation





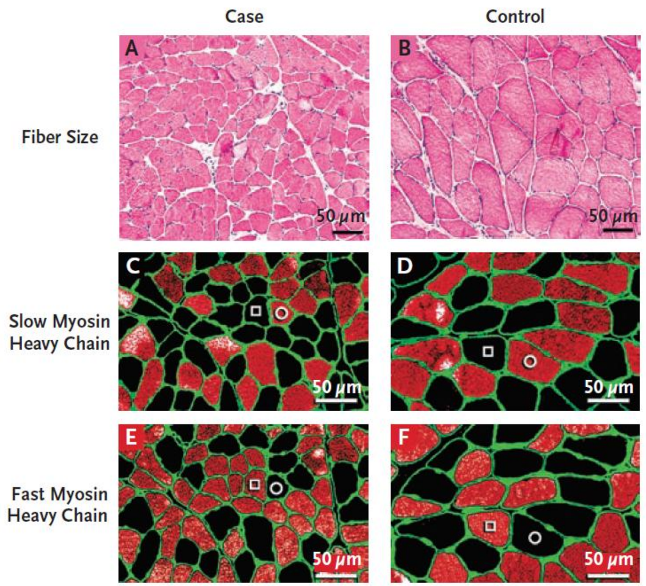
*Yoshida T, **Amato** BP, et al. PMID: 24199628*
Am J Respir Crit Care Med. 2013 Dec 15;188(12):1420-7

Spontaneous breathing in ARDS

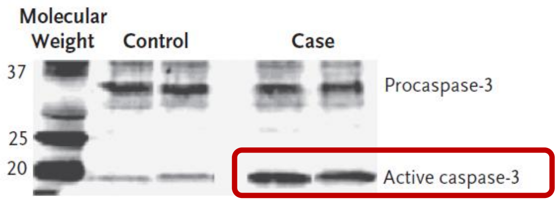
YES

Rapid disuse atrophy of diaphragm fibers in mechanically ventilated humans

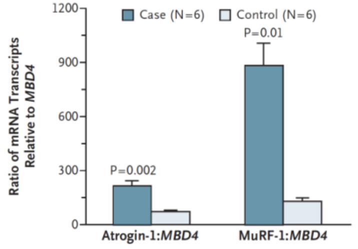
- **Background**: Diaphragm inactivity post mechanical ventilation for **18 hours in animals.**
- **Study-design**:
  - ✓ Case: Costal diaphragms of **14 brain-dead organ donors**. (**MV:** 18-69 hours)
  - ✓ Control**: Intraoperative diaphragm-biopsy** of 8 patients. (**MV: 2-3 hours**).



Active caspase-3 (protein degradation)



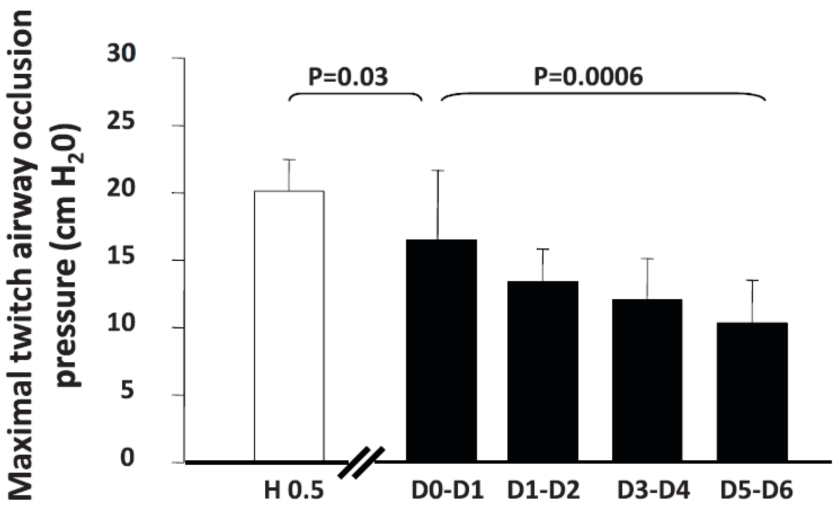
Atrogin-1/MuRF-1 (ubiquitin ligases)

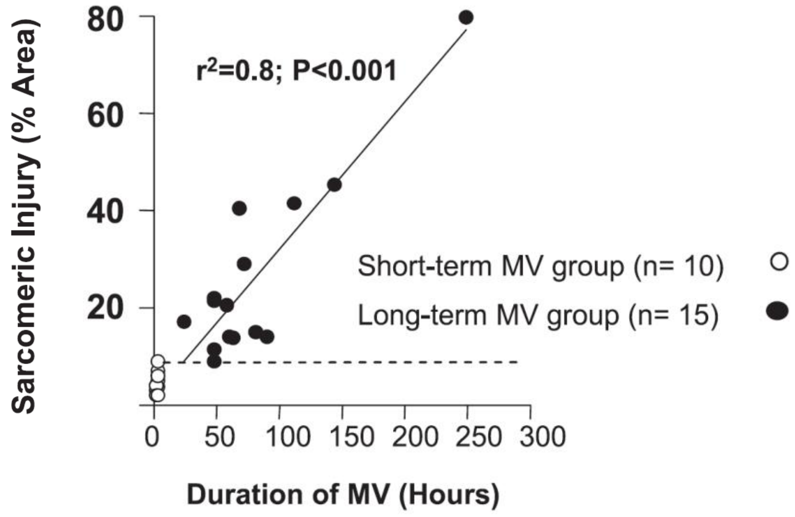


Levine S. et al.
N Engl J Med. 2008 Mar 27;358(13):1327-35.

Rapidly progressive diaphragmatic weakness and injury during mechanical ventilation in humans

Dose-response



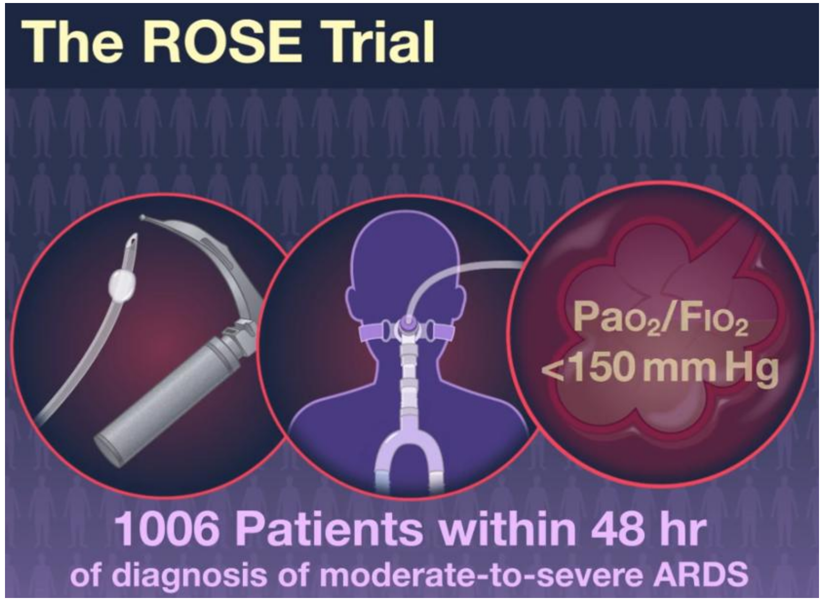


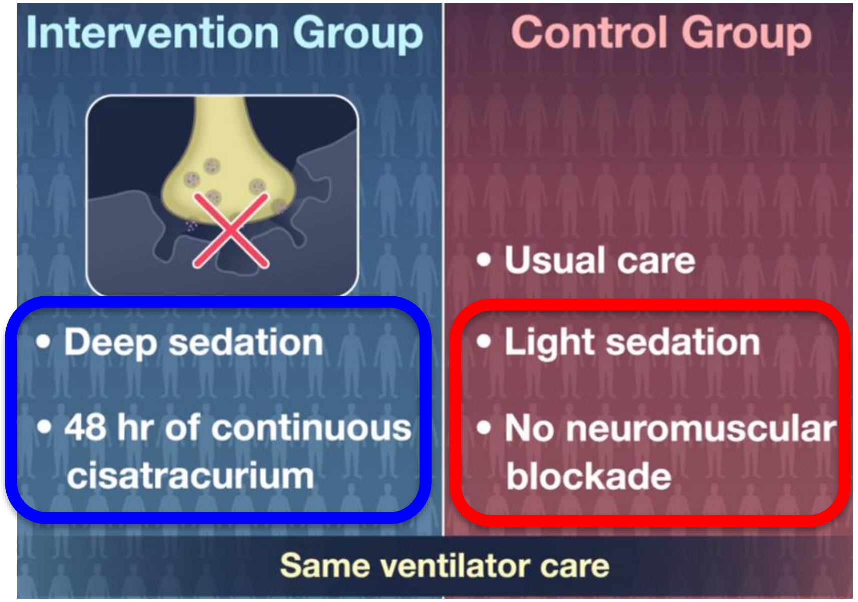
Jaber S. et al. PMID: 20813887
Am J Respir Crit Care Med. 2011 Feb 1;183(3):364-71.

Early Neuromuscular Blockade in the Acute Respiratory Distress Syndrome

lightly sedated **(RASS 0 to -1)**

ROSE trial





PEEP of ≥8 cm

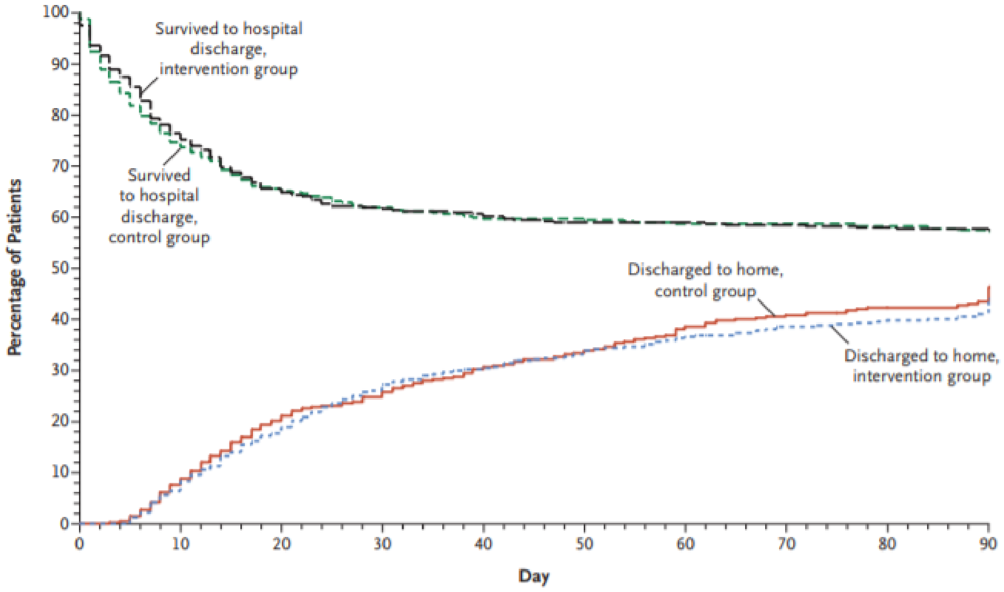
1,408 ➔ early stopped

Marc Moss

Moss M et al. PETAL Clinical Trials Network. PMID: 31112383
*Prevention and Early Treatment of Acute Lung Injury **(PETAL)***
N Engl J Med. 2019 May 23;380(21):1997-2008.

Early Neuromuscular Blockade in the Acute Respiratory Distress Syndrome

ROSE trial



PETAL Clinical Trials Network. PMID: 31112383
Prevention and Early Treatment of Acute Lung Injury (PETAL)
N Engl J Med. 2019 May 23;380(21):1997-2008.

Early Neuromuscular Blockade in the Acute Respiratory Distress Syndrome

ROSE trial

1,408 → 1006 **early stopped**

Adverse Events

ICU-acquired weakness

- **At Day 7**: 41.0% vs. 31.3% (Difference -9.7, 95% CI -21.5 to 2.1)
- **At Day 28**: 46.8% vs. 27.5% (Difference -19.4, 95% CI -38.2 to -0.6)

Serious adverse events

- 35 events vs. 22 events (P=0.09)
- **Barotrauma**: 4.0% vs. 6.3% (P=0.12)
- **Serious adverse cardiovascular events**: 14 events vs. 4 events (P = 0.02)

Cardiac arrest 6:2

System/disorder	Event	Severity	Intervention	Control
Blood/lymphatic	Methemoglobinemia	Serious	2	0
Cardiac	Complete atrioventricular block	Serious	1	0
	Atrial fibrillation (paroxysmal)	Non-Serious	1	0
	Atrial fibrillation w/ rapid vent response	Serious	1	0
	Bradycardia	Serious	1	0
		Non-Serious	1	0
	Cardiac arrest	Serious	6	2
		Non-Serious	0	2
	Cardiac arrhythmia (NOS)	Non-Serious	1	0
	3rd degree atrioventricular block	Serious	0	1
	Myocardial infarction	Serious	1	1
	Serious prolonged bradycardia	Non-Serious	1	0
	Tachycardia	Non-Serious	1	0
	Supraventricular tachycardia	Serious	1	0
	Torsades De Pointe	Serious	1	0
	Vasovagal reaction	Non-Serious	0	1
	Ventricular tachycardia	Serious	2	0

PETAL Clinical Trials Network. PMID: 31112383
Prevention and Early Treatment of Acute Lung Injury (PETAL)
N Engl J Med. 2019 May 23;380(21):1997-2008.

Early Paralytic Agents for ARDS?

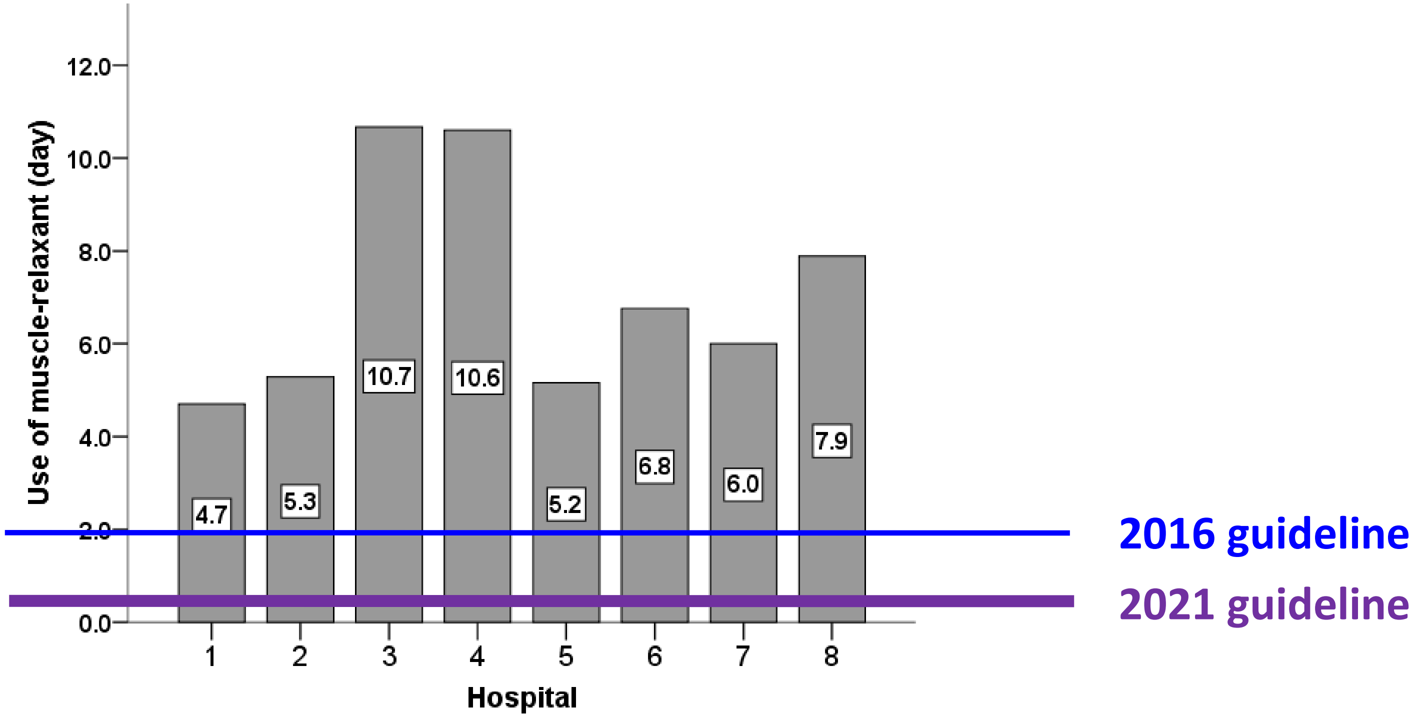
Yes, No, and Sometimes.


Slutsky AS, Villar J.
N Engl J Med. 2019 May 23;380(21):2061-2063.

- Therapeutic strategies in ARDS should ideally be tailored to the specific underlying disease or injury mechanism at any given point in time, rather than being applied uniformly to all patients.
- Early paralytic agents for ARDS? Given their long-term neuromuscular safety profile in the ROSE trial, we suggest that paralytic agents can sometimes be used, when physiologically and clinically indicated.

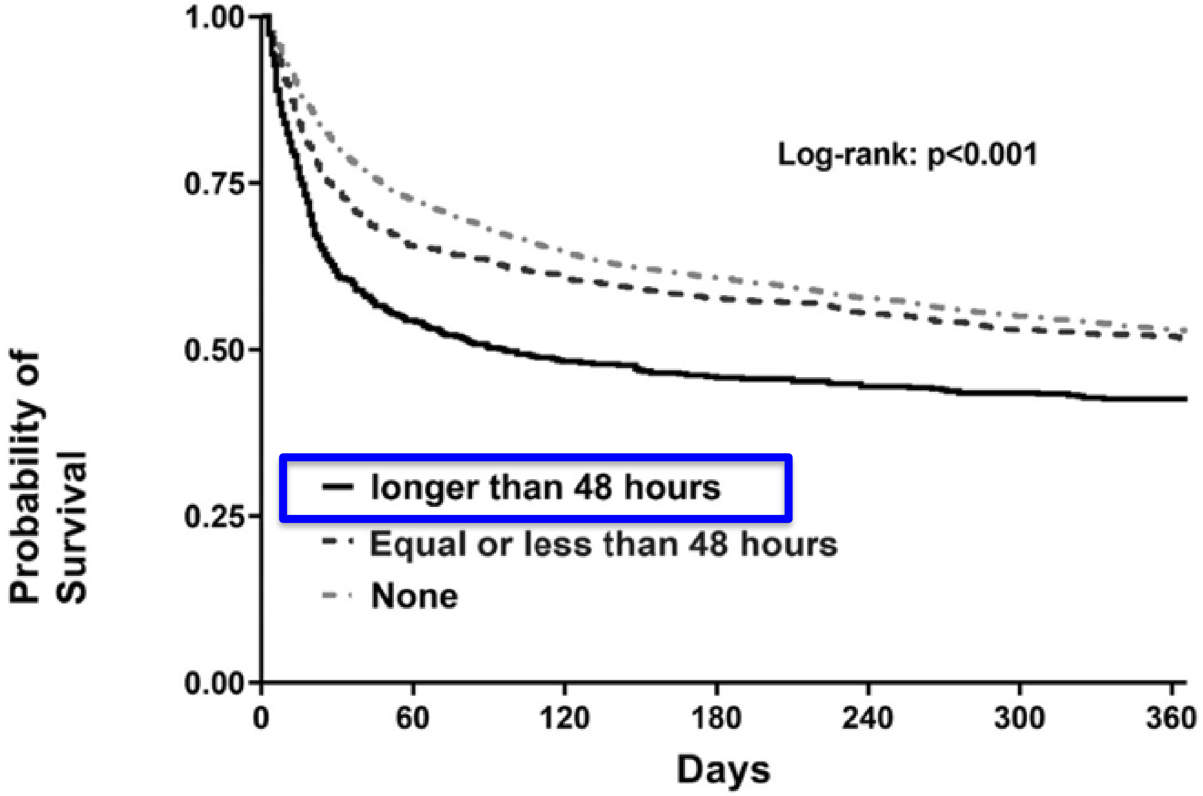
We might/should/must reduce the use of

NMBA in subjects with ARDS in Taiwan



Taiwan Severe Influenza Research Consortium (TSIRC) investigators.

Prolonged use of neuromuscular blocking agents is associated with increased long-term mortality in mechanically ventilated medical ICU patients: a retrospective cohort study



Number at risk

exceed 48hrs	535	291	258	246	238	233	228
Equal or less than 48 hrs	765	502	466	441	425	405	398
None	4409	3199	2854	2681	2546	2427	2337

Lin Chun et al.
J Intensive Care. 2023 Nov 17;11(1):55.

Mechanical Ventilation to Minimize Progression of Lung Injury in Acute Respiratory Failure

Patient Self-Inflicted Lung Injury

- **High respiratory drive**
- **High Pes swings**
- **Pendelluft**

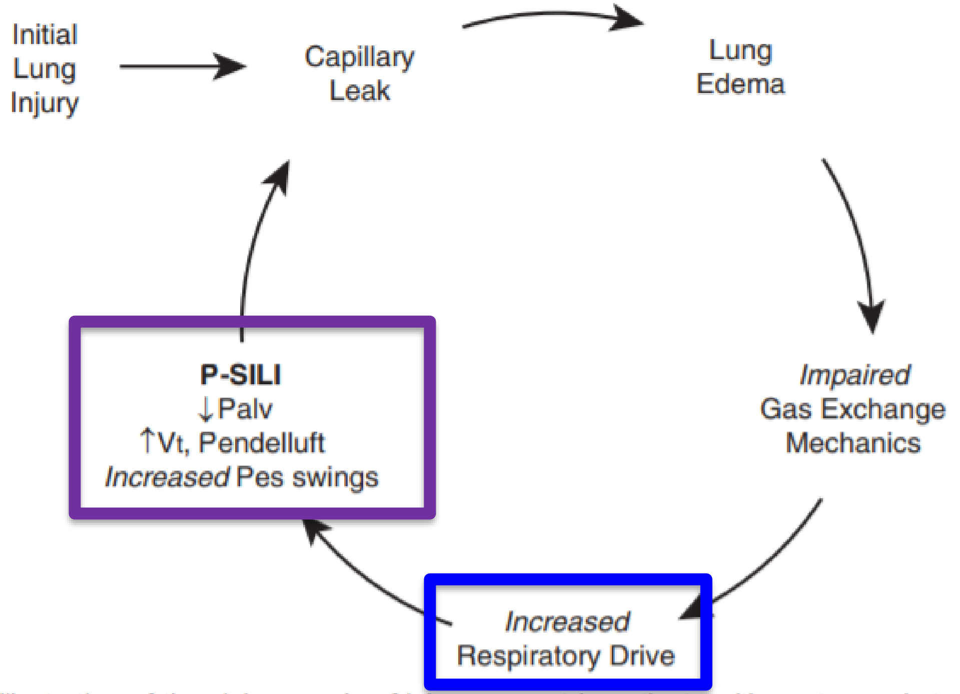


Figure 2. Illustration of the vicious cycle of injury present in patients with acute respiratory failure. Palv = alveolar pressure; Pes = esophageal pressure swings; P-SILI = patient self-inflicted lung injury.

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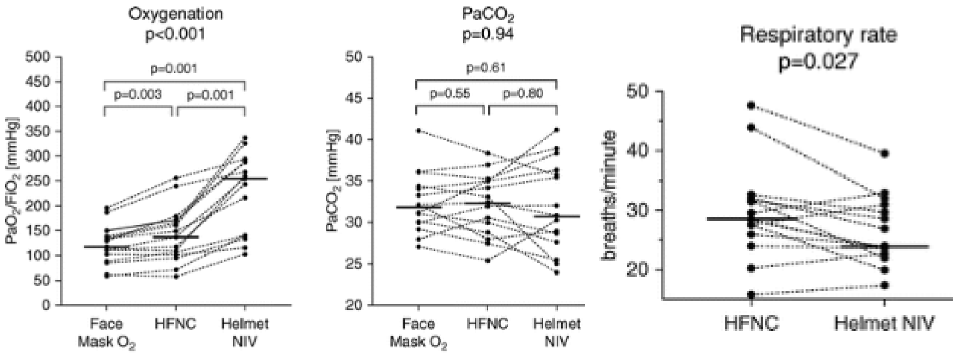
Laurent Brochard, Arthur Slutsky, Antonio Pesenti

Am J Respir Crit Care Med . 2017 Feb 15;195(4):438-442. PMID: 27626833

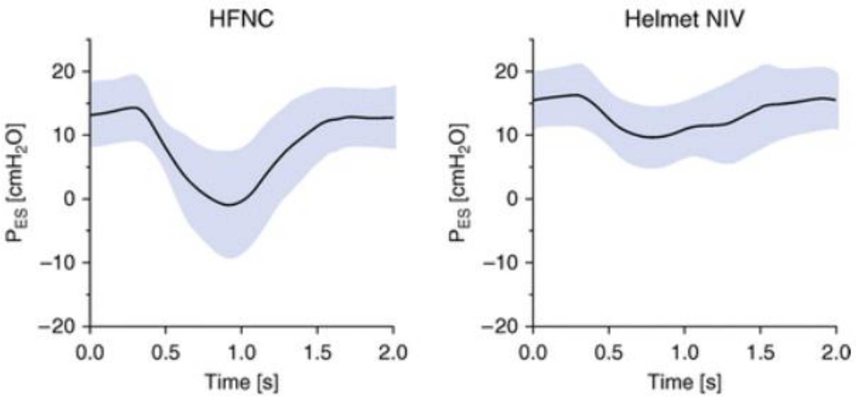
Physiological Comparison of High-Flow Nasal Cannula and Helmet Noninvasive Ventilation in Acute Hypoxemic Respiratory Failure

- Fifteen patients with hypoxemia with PaO2/FiO2 < 200 mm Hg
- NIV (**PEEP ≥ 10 cm H2O**, pressure support = 10-15 cm H2O)
- HFNC (**50 L/min**)

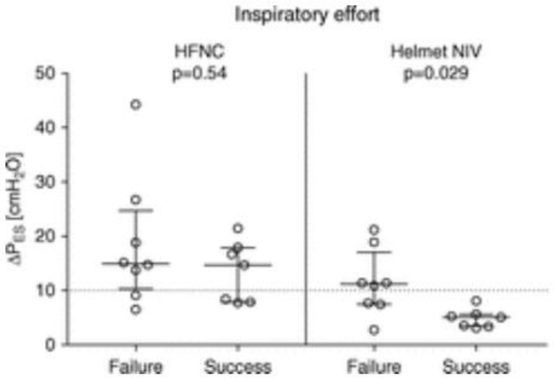
Oxygenation, PaCO2, Respiratory rate



Pes: pleural pressure



Inspiratory effort [P-SILI]



Conclusions: As compared with HFNC in hypoxemic respiratory failure, helmet NIV improves oxygenation, reduces dyspnea, **inspiratory effort**, and simplified pressure–time product, with similar transpulmonary pressure swings, PaCO2, and comfort.

Domenico Luca Grieco et al.
Am J Respir Crit Care Med. 2020 Feb 1;201(3):303-312.

Low versus high positive end expiratory pressure in noninvasive ventilation for hypoxemic respiratory failure: a multicenter randomized controlled trial

- Design: Multicenter, open-label, randomized controlled trial across seven ICUs in China.
- Population: Adults aged 16–85 years with acute hypoxemic respiratory failure ($PaO_2/FiO_2 \leq 300$ mmHg, $PaCO_2 \leq 50$ mmHg), anticipated NIV >12 h, and preserved consciousness (GCS ≥13).
- Interventions:
  - Low PEEP Group: PEEP 5 cmH_2O, IPAP 10–20 cmH_2O.
  - High PEEP Group: PEEP 10–15 cmH_2O, IPAP 15–20 cmH_2O.

The First Affiliated Hospital of Chongqing Medical University,
Yuzhong District, Chongqing, China.

Jun Duan, et al.
Intensive Care Med. 2025 May;51(5):861-869.

Low versus high positive end expiratory pressure in noninvasive ventilation for hypoxemic respiratory failure: a multicenter randomized controlled trial

- NIV failure occurred in 43% (82/190) of the low PEEP group versus 32% (61/190) of the high PEEP group (absolute difference 11.1%, 95% CI 1.3–20.5, p=0.034).
- 28-day mortality: 41% in the low PEEP group and 30% in the high PEEP group (absolute difference 11.1%, 95% CI 1.4–20.4, p=0.032).
- Mediation analysis: 77% of the observed benefit of high PEEP on NIV failure was attributed to improvements in PaO_2/FiO_2; 14% was mediated through lower tidal volume.

Jun Duan, et al.

Intensive Care Med. 2025 May;51(5):861-869.

Patient Self-Inflicted Lung Injury: P-SILI

April 21, 2020
Critical Care Compendium CCC

- Patient self-inflicted lung injury (P-SILI) is a controversial, emerging concept.
- Concerns about P-SILI must be balanced against the harms from prolonged controlled ventilation, over-sedation, and paralysis, when allowing patients to breathe spontaneously.

Dr Chris Nickson
Alfred ICU in Melbourne.

Practical suggestions

- Controlled ventilation is a preferred strategy for early severe ARDS
- Timing of the transition is complex due to potential for P-SILI balanced against the harms from prolonged controlled ventilation, over-sedation, and paralysis
- Optimisation of patient-ventilator synchrony is necessary for a safe transition to spontaneous breathing
- Novel tools: esophageal manometry and diaphragm electromyography

April 21, 2020
Dr Chris Nickson
Alfred ICU in Melbourne.

建議：間歇性 NMBA 注射優於持續輸注
Intermittent NMBA Boluses over Continuous Infusion

建議聲明（Conditional Recommendation，Moderate Certainty）對於敗血症合併中重度 ARDS 的成人，建議使用間歇性 NMBA 注射，而非 NMBA 持續靜脈輸注。

For adults with sepsis and moderate-severe ARDS, we "suggest" using intermittent NMBA boluses over continuous NMBA infusion.

與 2021 比較（Revisited）

2021 版建議間歇性 NMBA（Moderate certainty）。2026 版維持相同立場，但根據 ROSE 試驗的長期隨訪數據及新 meta-analysis，對建議的理由進行了更新闡述。

關鍵試驗：ROSE 試驗（2019）

ROSE 試驗結果

NMBA 持續輸注 48 小時組 vs. 輕度鎮靜常規護理組，90 天死亡率無顯著差異（42.5% vs. 42.8%），推翻了 ACURASYS 試驗的早期發現

持續輸注的副作用

長期 NMBA 與 ICU-acquired weakness（ICU 獲得性虛弱）顯著相關，影響患者功能恢復及 ICU 脫機

間歇性注射的適應症

當出現嚴重人機不同步、需深度鎮靜、俯臥位執行困難或平台壓持續過高時，可考慮間歇性使用 NMBA

Take home message

- Trigger, limit, and cycle variables constitute the fundamental phase components of mechanical breath delivery.
- Systematic monitoring of pulmonary mechanics, including Pplat, driving pressure, auto-PEEP and application of capnography are crucial to guide effective ventilation.
- Neuromuscular blockade serves as a critical intervention to mitigate patient self-inflicted lung injury by suppressing excessive spontaneous inspiratory drive.

Thank you.

Chao, Wen-Cheng,
M.D. Ph.D. [ORCID 0000-0001-9631-8934]

Contact information
e-mail. cwc081@vghtc.gov.tw