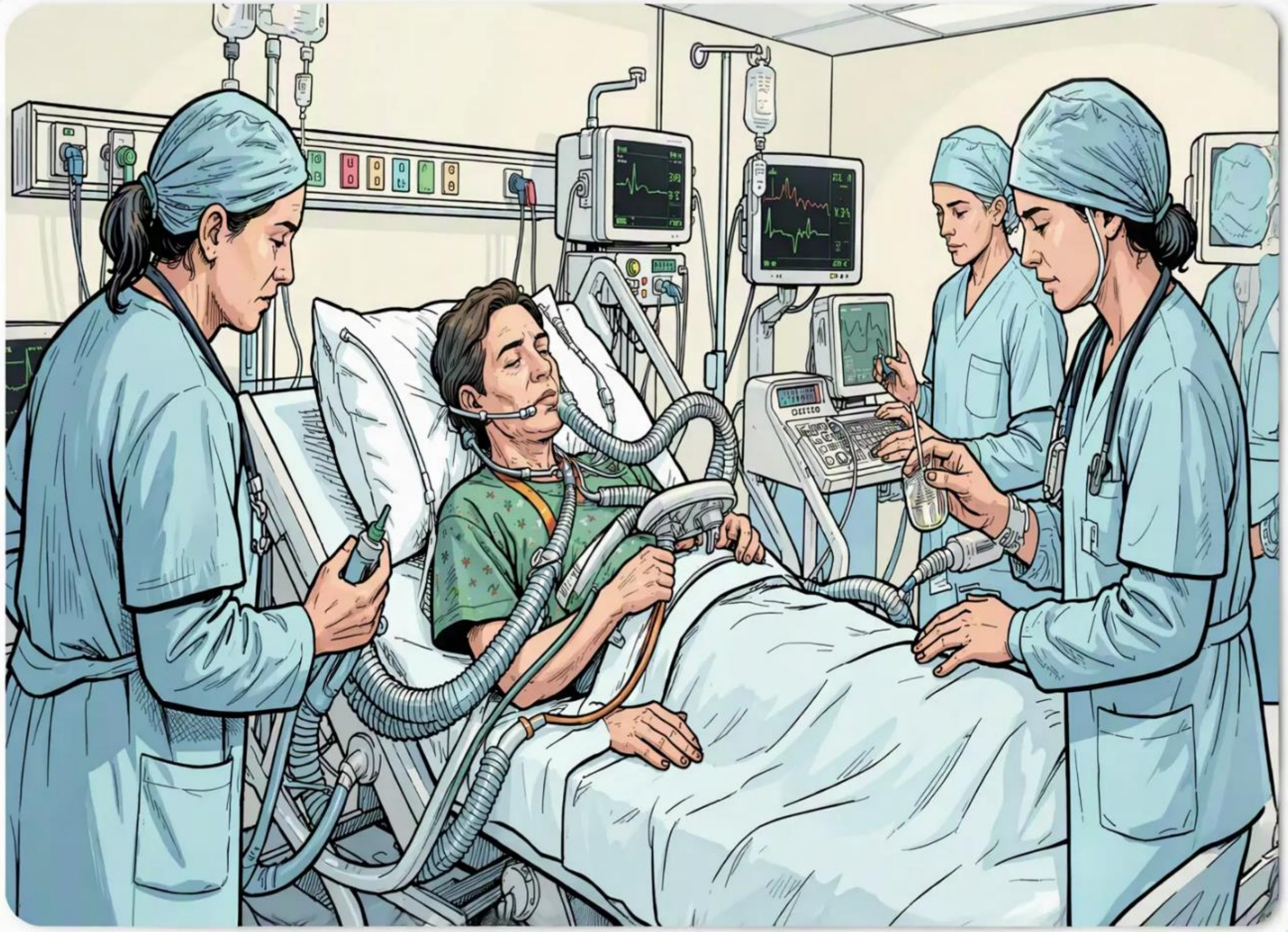
臺北榮總

Design and maintenance of mechanical ventilator: conventional and novel modes

從設計原理到臨床實戰——臨床必備的呼吸器邏輯

Date: 08/16/2026

Speaker: Yu-chun Chen RT



Control ventilation

適用於自主呼吸消失或深度鎮靜狀態

Assist control ventilation

機器同步患者呼吸，主要在降低呼吸功

臨床目標

在最小化呼吸器相關肺損傷（VILI）與最大化患者舒適度間尋求動態平衡

Outline

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- ✓ Design Principles
- ✓ Conventional Modes
- ✓ Novel Modes
- ✓ Maintenance & Troubleshooting
- ✓ Future Perspectives

視病猶親
追求卓越

Design Principles

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核心硬體架構：氣體輸送系統、比例閥（Proportional valves）、微處理器控制迴路。

感測與監測技術：壓力（Pressure）、流量（Flow）、容積（Volume）感測器的設計精度與數據回饋。

安全防護機制：電源備援系統、氣源中斷保護、高 / 低壓警報設定與釋壓閥設計。

視病猶親
追求卓越

四大要素

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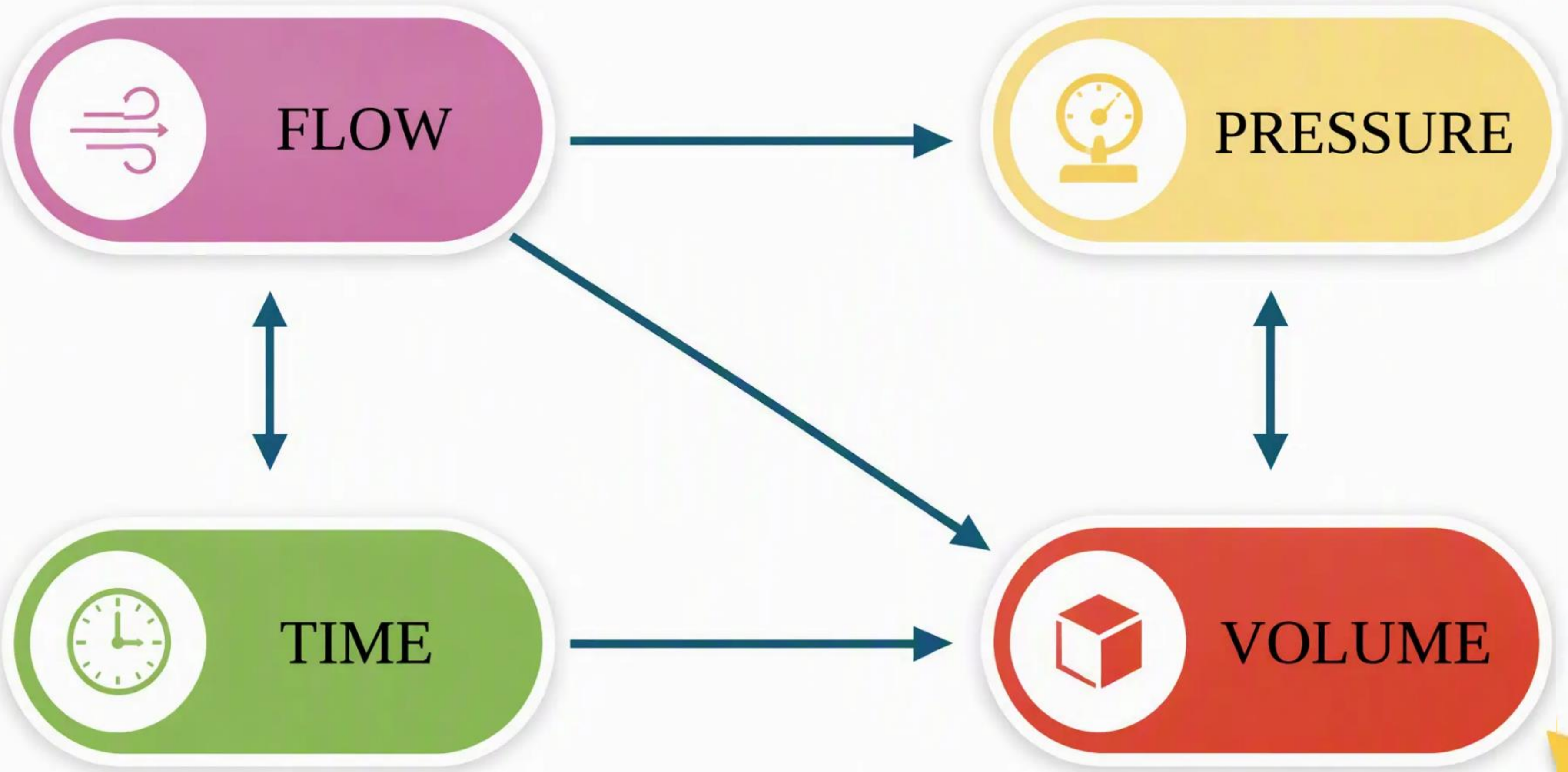

視病猶親
追求卓越

要素	意義	例如
驅動 Trigger	如何啟動呼吸器送每一口氣	time、 pressure、 flow、 neutrally
限制 Limit	通氣模式的主軸	Volume or pressure
結束 Cycle	什麼條件進入吐氣期	Time, flow, volume, neurally

Conventional Modes

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▶ Volume ventilation

- Controlled mandatory ventilation (CMV)/Volume-control (VC-A/C)
- Intermittent Mandatory Ventilation (IMV)/Synchronized Intermittent Mandatory Ventilation (SIMV)
- Volume support

▶ Pressure ventilation

- Pressure control
- Intermittent Mandatory Ventilation (IMV)/ Synchronized Intermittent Mandatory Ventilation (SIMV)
- Pressure support

Waveform- A/C

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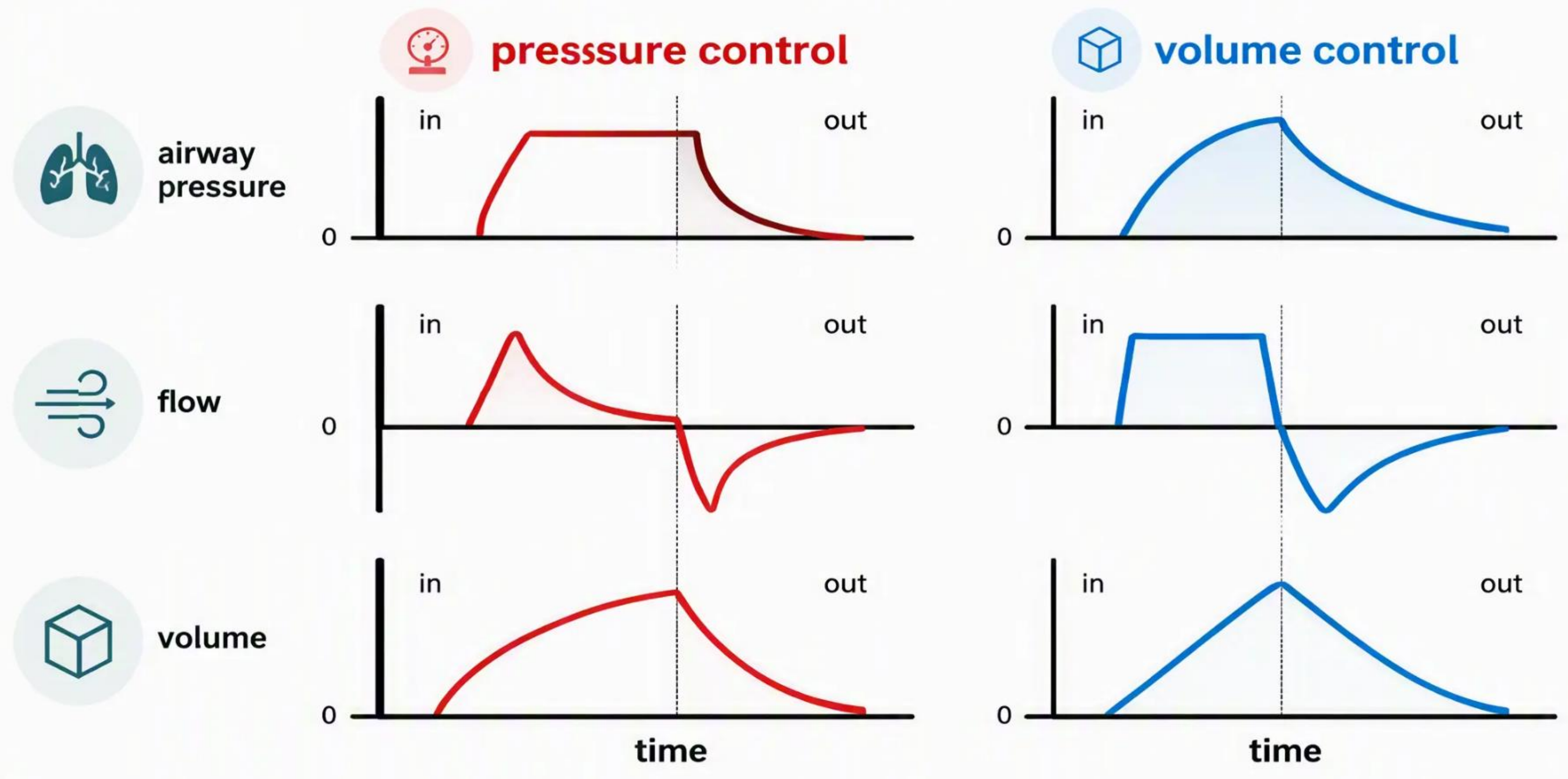
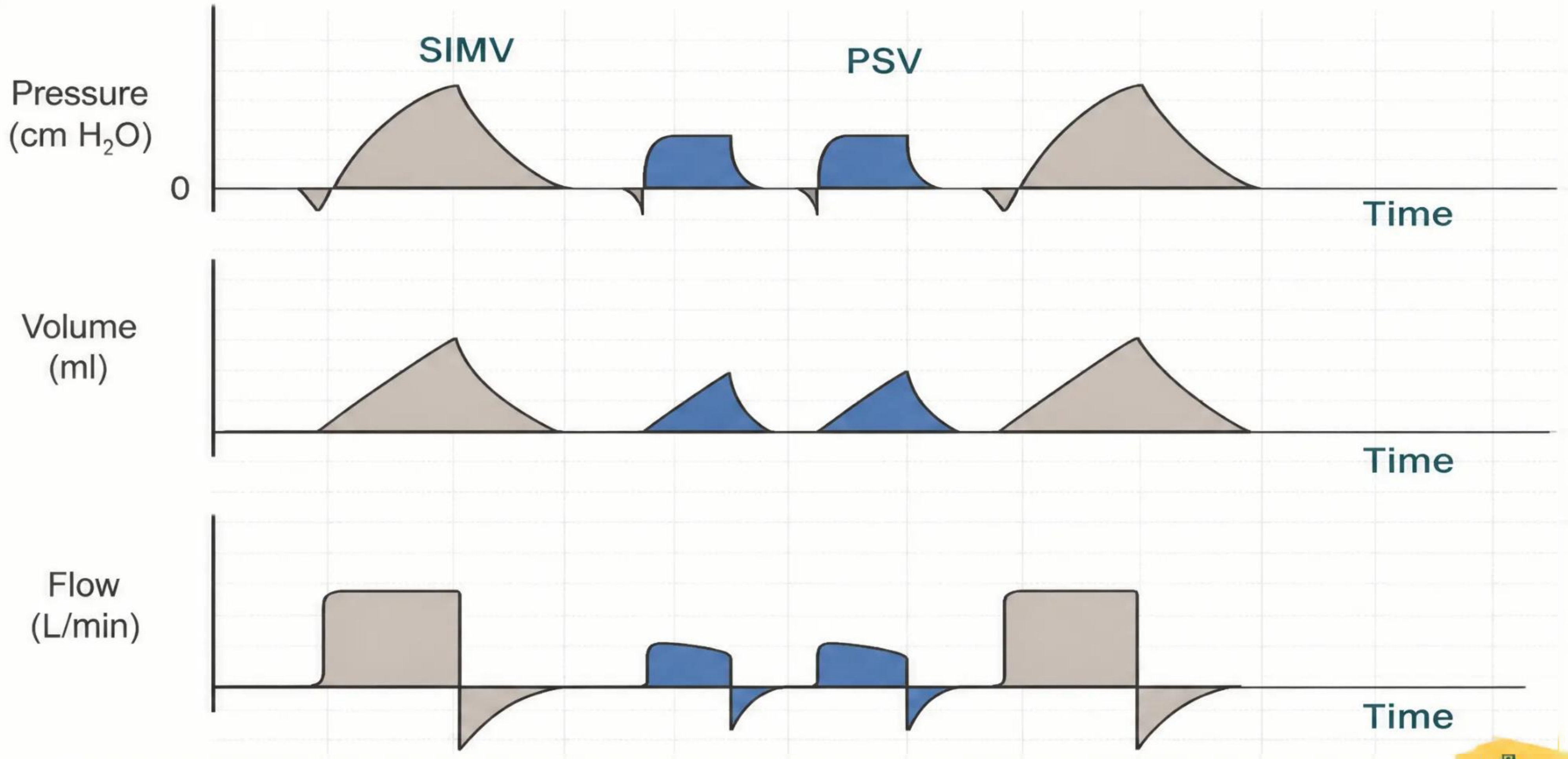
PRESSURE VS VOLUME CONTROL

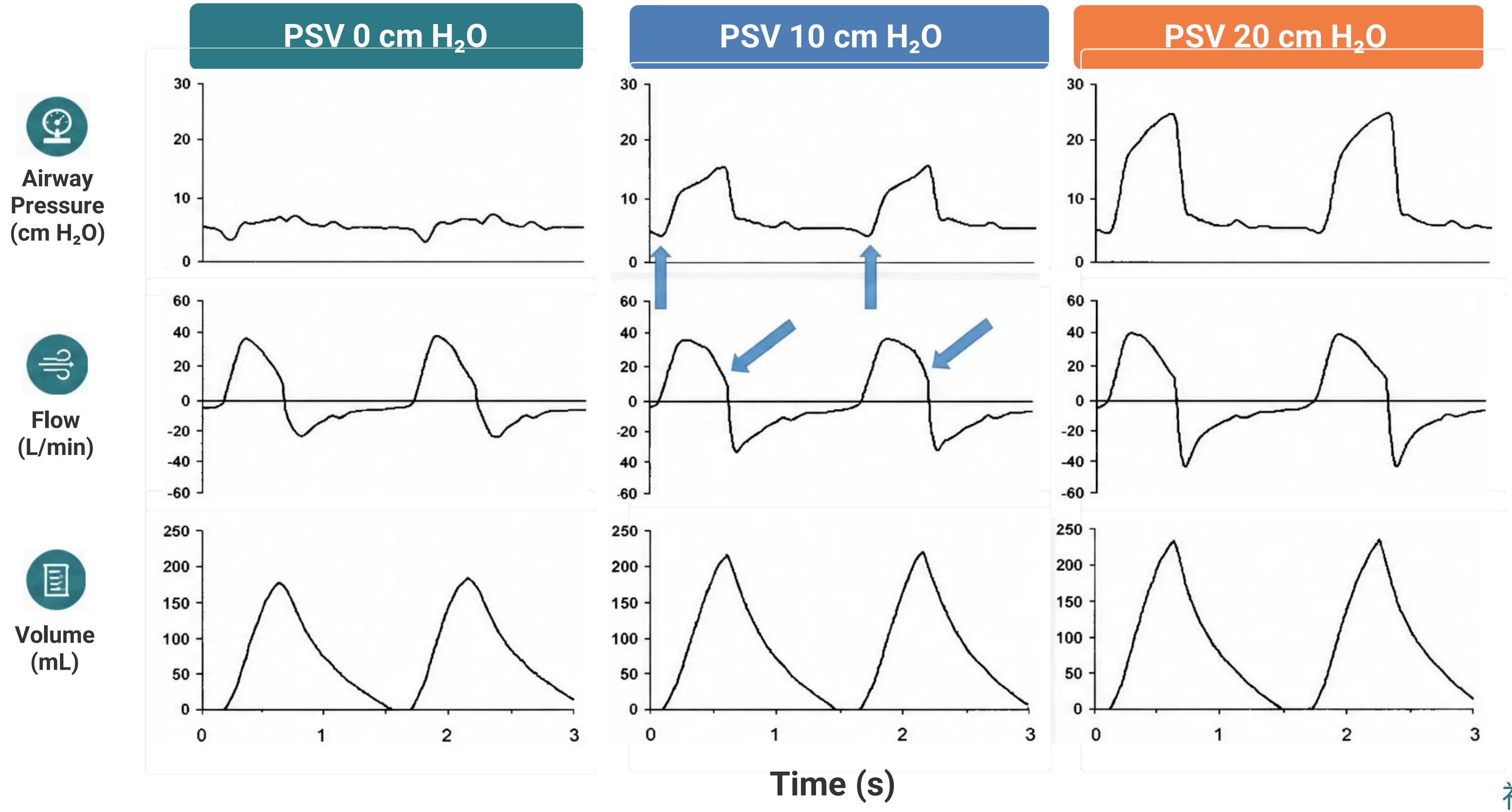


視病猶親
追求卓越

Waveform – SIMV + PS



Waveform – PS



視病猶親
追求卓越

Conventional Modes

	Mode	Trigger	Limited	Cycled	Variable	Setting
Full support	VC(A/C)	Patient or Time	Volume	Volume Time	R.R. Pressure	Volume Flow (Ti) RR.
Full support	PCV	Patient or Time	Pressure	Time	Flow Volume R.R.	Pressure Ti RR.
partial support	SIMV +PS	Patient or Time	Volume Pressure	Volume Pressure Time	Flow Volume R.R.	All
partial support	PS	patient	Pressure	Flow	Flow Volume R.R.	Pressure
partial support	CPAP	patient		Patient	Flow Volume R.R.	Pressure

Novel Modes

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▶ CLOSED-LOOP SYSTEMS

呼吸器透過感測器每秒數百次計算，實現「自動調整」ADAPTIVE SUPPORT VENTILATION （ASV），機器根據奧蒂斯公式(Otis equation）自動尋找最省力的呼吸頻率。

▶ DUAL CONTROL MODES

PRESSURE REGULATED VOLUMECONTROL(PRVC) 利用前一次呼吸的順應性，計算下一次所需的最低壓力（結合 VCV 與 PCV 優點），自動用最低的吸氣壓力來達到該容積，避免不必要的高壓（BAROTRAUMA）。

▶ OPEN AIRWAY MODES

Airway Pressure Release Ventilation(APRV) 的設計，雙相氣道正壓，允許病人在高壓基線下自由呼吸的特殊閥門設計。

▶ ADVANCED SPONTANEOUS MODES

NEURALLY ADJUSTED VENTILATORY ASSIST(NAVA), 大腦一發出想呼吸的訊號，呼吸器立刻送氣，完全打破傳統「壓力或流速觸發」的延遲，是目前人機同步性最高的模式。

視病猶親
追求卓越

CLOSED-LOOP SYSTEMS

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ADAPTIVE SUPPORT VENTILATION (ASV)

ASV

▶ Definition

- is advanced closed-loop control mode of mechanical ventilation designed to provide a user-set minimum MinVol with an optimal breathing pattern based on the least work of breathing and the minimum force of breathing principle.

Classification of modes - ASV

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- ▶ Covers both controlled and spont/assisted ventilation – automatically transitions between
- ▶ IN CONTROLLED (no spontaneous breathing):
  - volume-targeted pressure controlled ventilation
- ▶ IN SPONT/ASSISTED:
  - volume targeted, variable pressure support ventilation

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追求卓越

Only three main parameter controls

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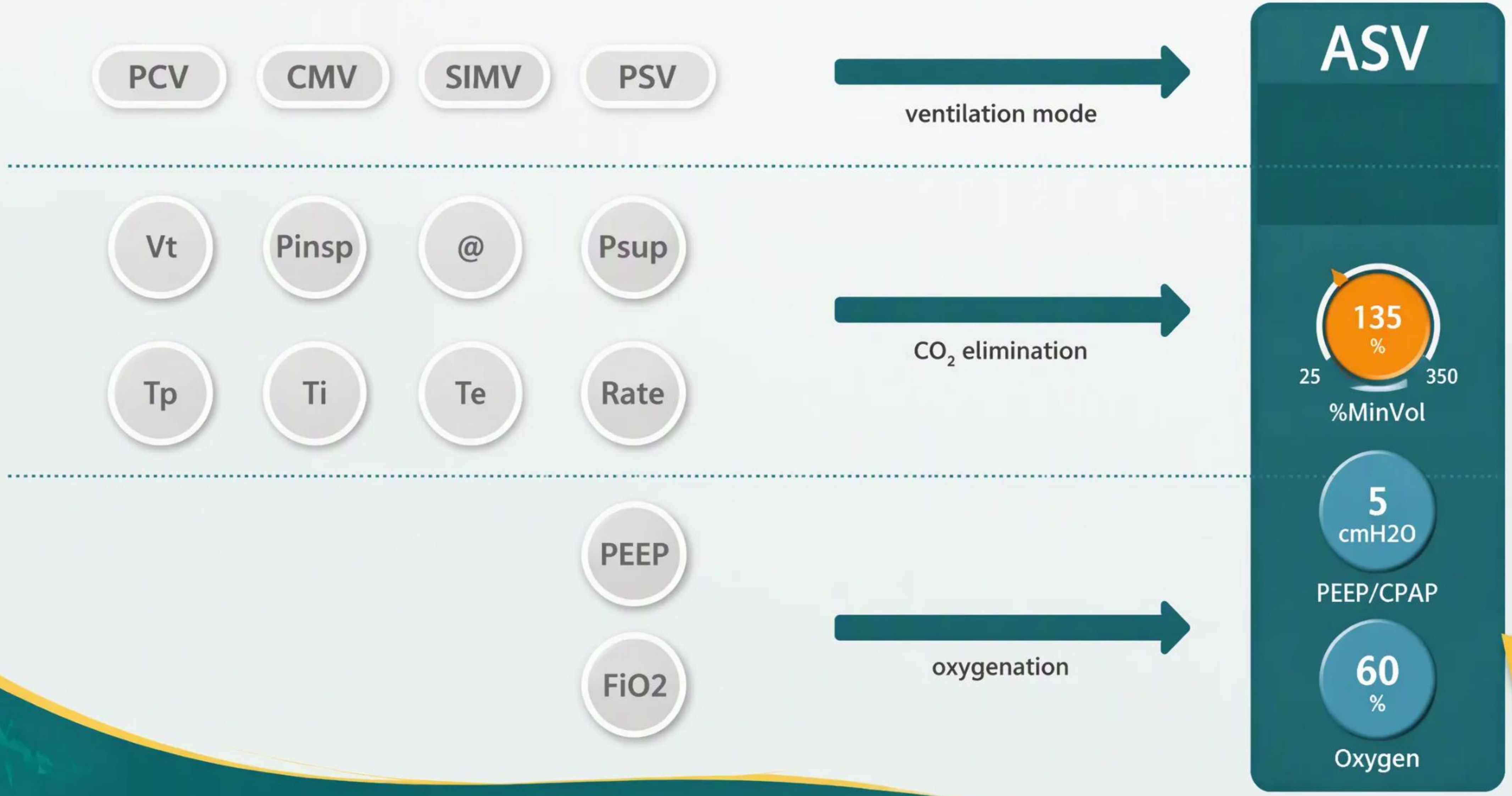

視病猶親
追求卓越

%MinVol control - ASV

minute volume normalized to IBW (kg)

(IBW – calculated based on selected patient gender & height)

100 % MinVol – express the basal ventilation requirements

IBW ≥ 30 kg

100 ml/min per kg IBW

e.g.

IBW = 75 kg

%MinVol = 100 %

Target MinVol = 7.5 l/min

Minute Ventilation - ASV

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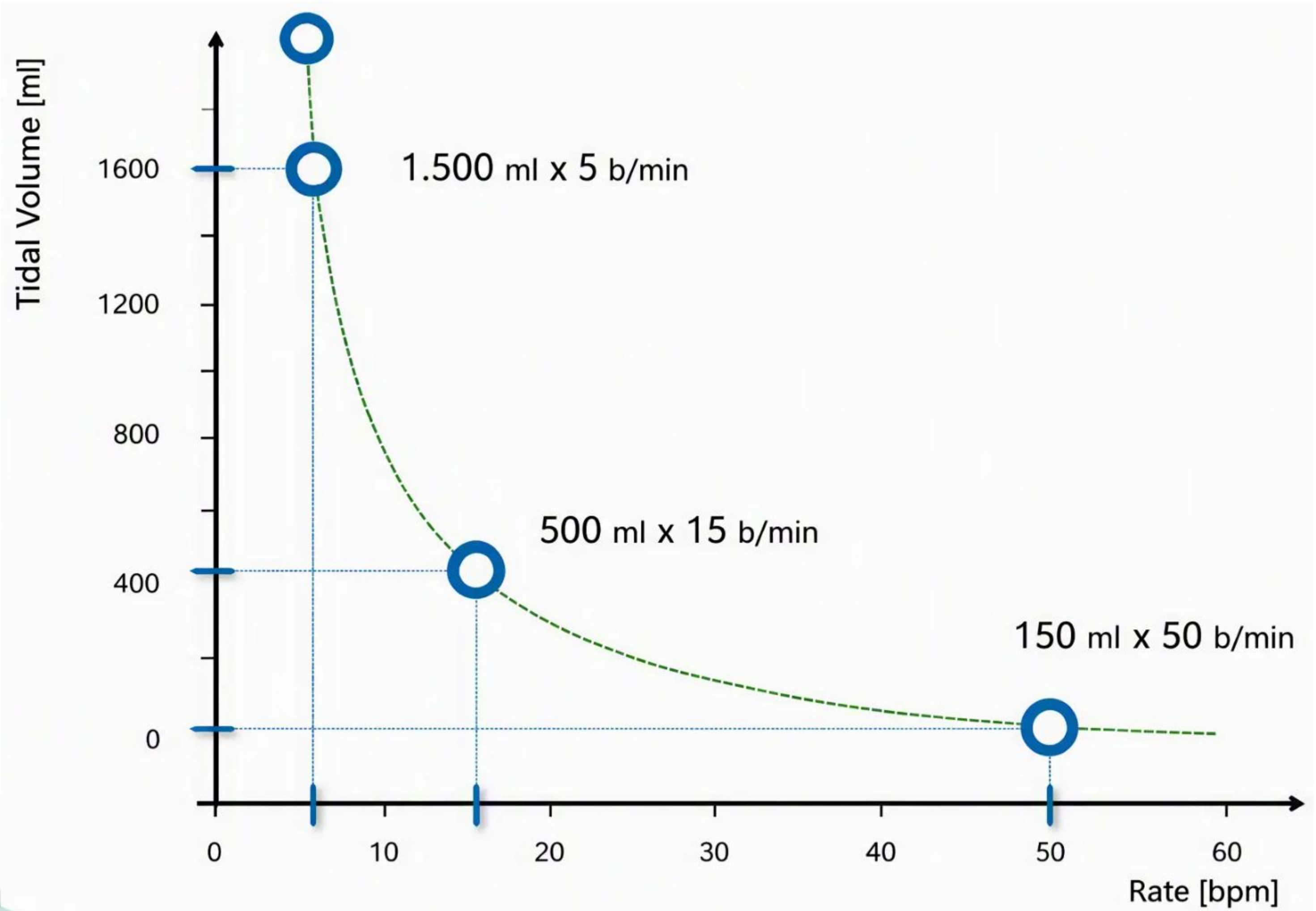

MinVol

7.5

l/min

Target

RR-VT combination

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追求卓越

WOB & respiratory rate dependency

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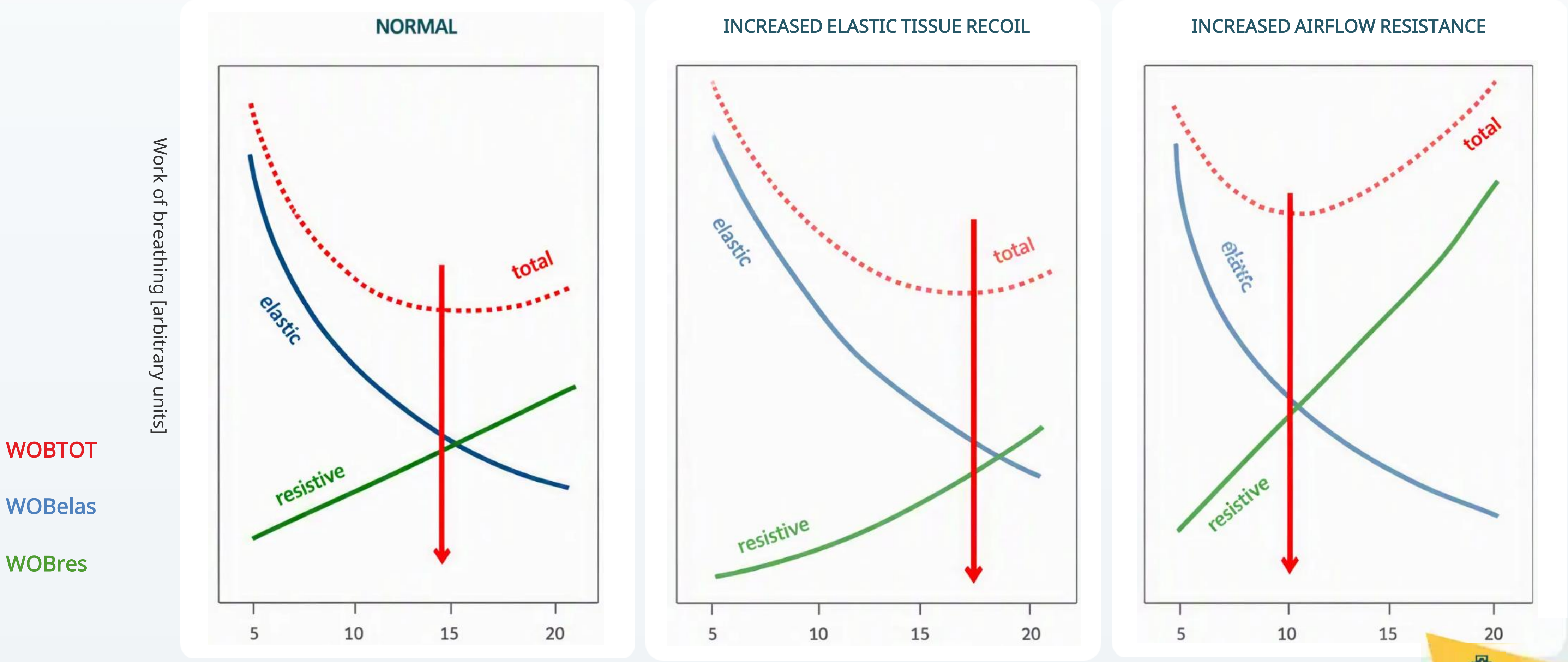

Respiratory frequency [1/min]

modified from:

Nunn JF. Applied Respiratory Physiology 3rd edition (1989)

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追求卓越

Target respiratory rate

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Adaptive Support Ventilation (ASV) 1.1

Otis' formula*

Minimum work or breathing

Mead's formula**

Minimum force or breathing

Two elements: RCexp and VA/VD – in common

*Otis AB, et al. Mechanics of Breathiq in Man. J App Physiol 1950;2:592-607.

**Mead, J. Control of respiratory frequency. Appl. Physiol. 1960; 15(3) : 325-336

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追求卓越

Closed loop control

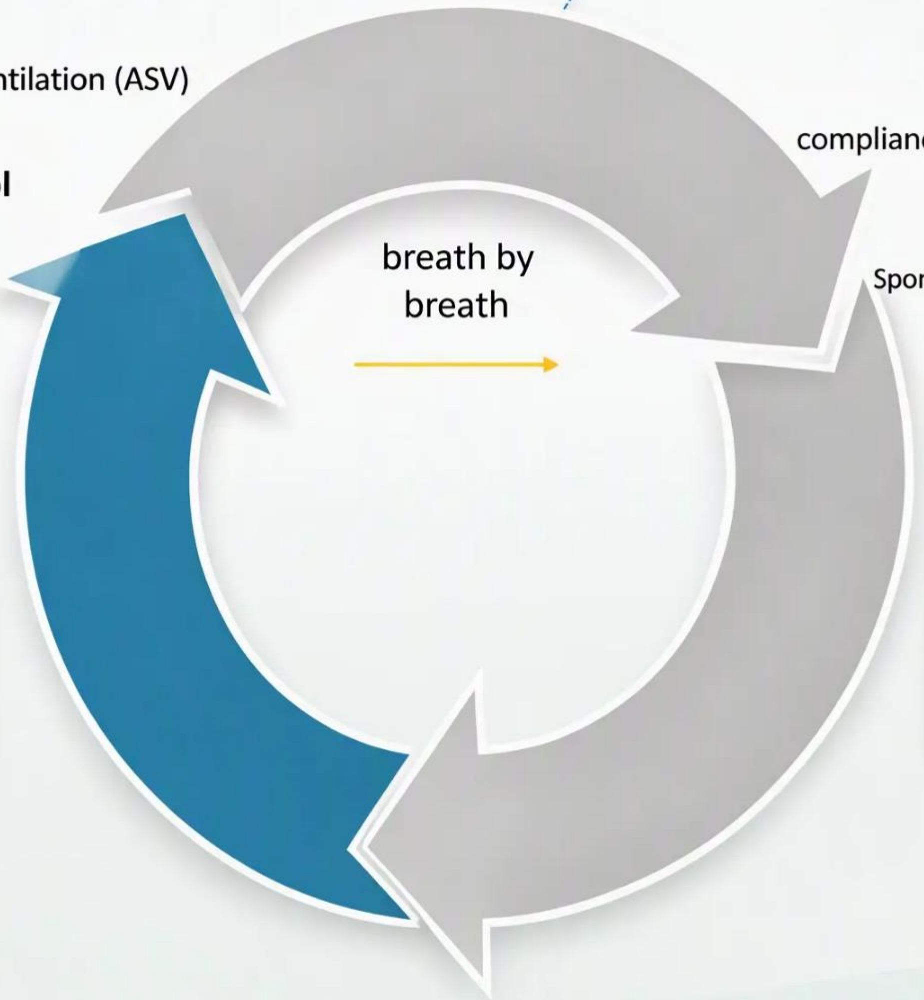
Pinsp, Ftotal, Tinsp

defined by clinician

Adaptive Support Ventilation (ASV)

Target MinVol

P_{ASV} limit



compliance & resistance

$\mathbf{RC_{exp}}$

Spontaneous activity

(RR) & $\mathbf{V_T}$

from patient

breath by breath

Achieve **target RR -** $\mathbf{V_T}$ **combination** by automatically adjusting **mandatory rate** and $\mathbf{P_{insp}}$*

ASV algorithm* calculates the optimal – **target RR-**$\mathbf{V_T}$ combination **“breathing pattern”**

*within the P_{ASV} limit (defined by the user)

ASV graph

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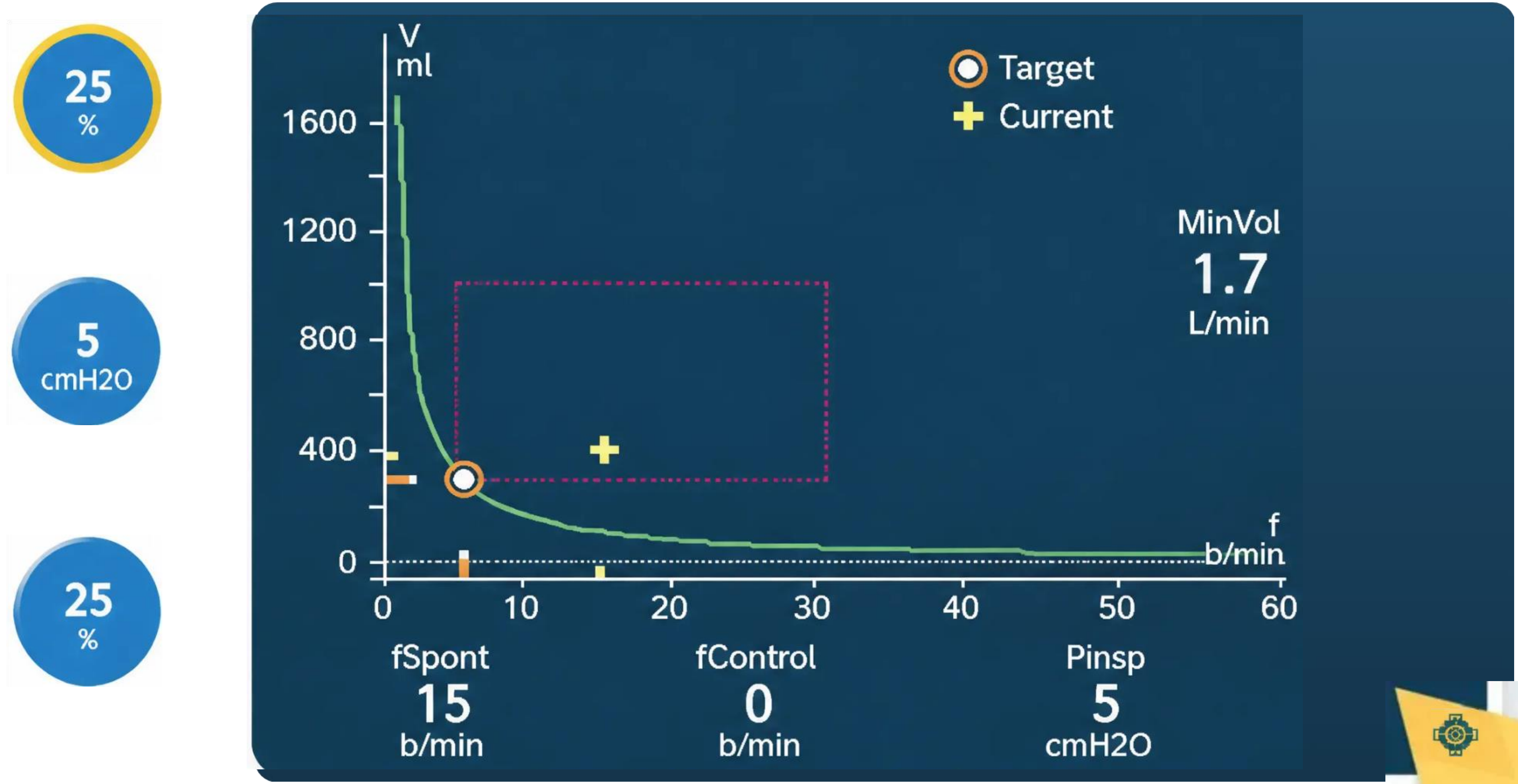
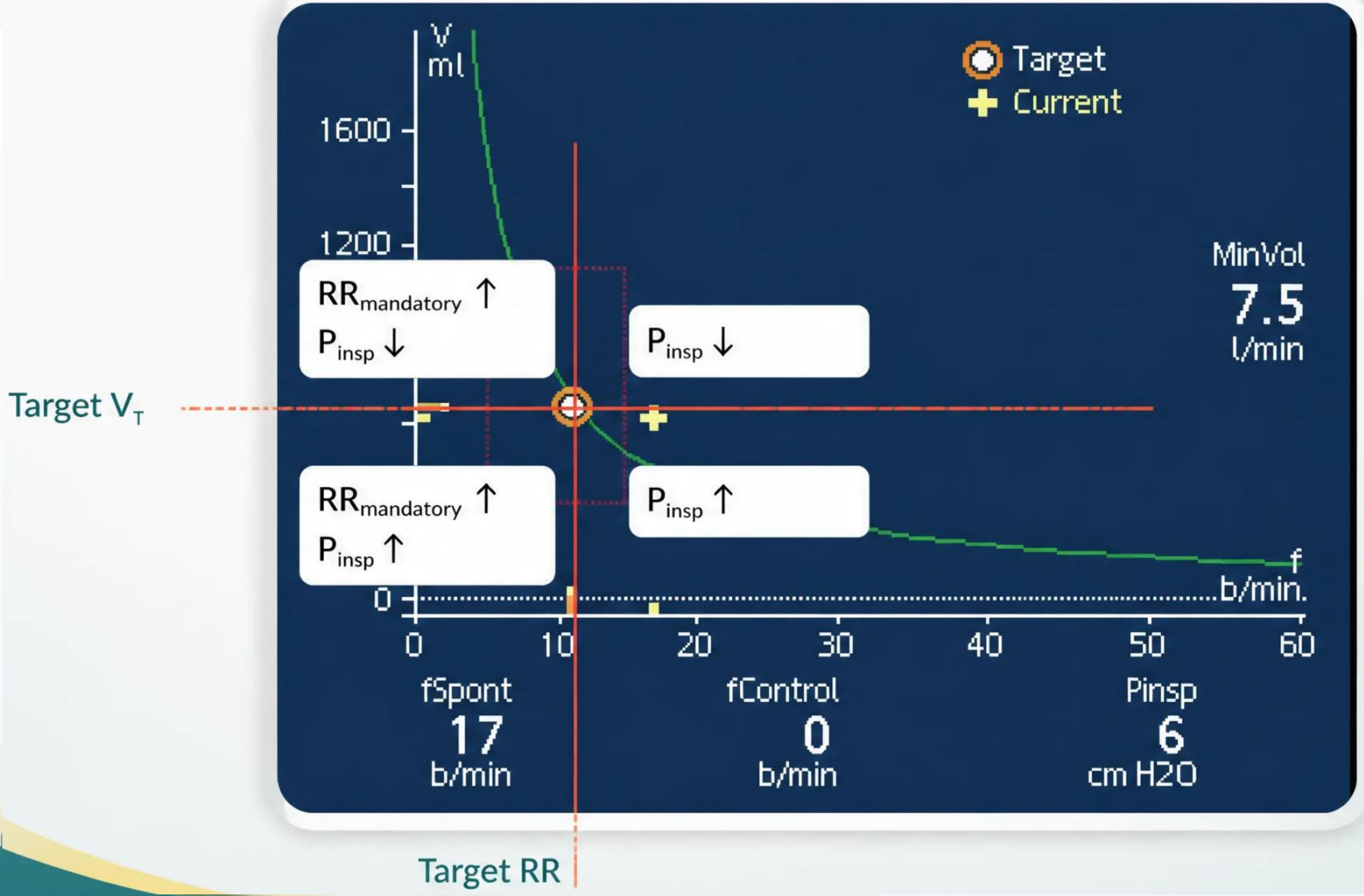


視病猶親
追求卓越


V
ml
1600
1200
0
Target
Current
MinVol
7.5
l/min
RR$_{mandatory}$ ↑
P$_{insp}$ ↓
P$_{insp}$ ↓
RR$_{mandatory}$ ↑
P$_{insp}$ ↑
P$_{insp}$ ↑
f
b/min.
0 10 20 30 40 50 60
fSpont
17
b/min
fControl
0
b/min
Pinsp
6
cm H2O
Target V_T
Target RR

ASV mode
下
達到脫離指數
的持續時間

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> Expert Rev Respir Med. 2021 Nov;15(11):1403-1413. doi: 10.1080/17476348.2021.1933450. Epub 2021 Jul 31.

Effectiveness, safety and efficacy of INTELLiVENT-adaptive support ventilation, a closed-loop ventilation mode for use in ICU patients – a systematic review

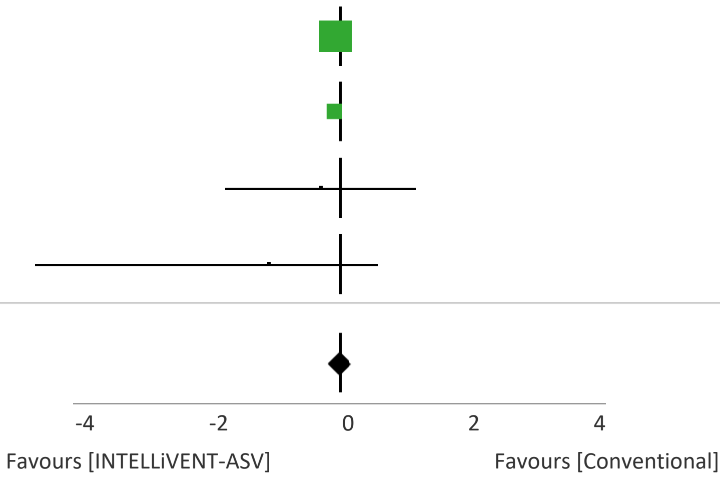
M Botta [1] , E F E Wenstedt [2] , A M Tsonas [1] , L A Buiteman-Kruizinga [1 3] , D M P van Meenen [1] , H H M Korsten [2 4] , J Horn [1 5] , F Paulus [1 6] , A G J H Bindels [2] , M J Schultz [1 7 8] , A J R De Bie [2 4]

視病猶親
追求卓越

▶ Forest plot of duration of mechanical ventilation

	INTELLiVENT-ASV			Conventional				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Beijers 2014	0.14	0.05	51	0.15	0.12	47	72.2%	-0.01 [-0.05, 0.03]
De Bie 2019	0.24	0.17	103	0.31	0.33	105	27.7%	-0.07 [-0.14, 0.00]
Arnal 2018	5.67	3.89	30	6.17	5.06	30	0.0%	-0.50 [-2.78, 1.78]
Bialais 2016	8.56	7.68	42	10.42	8.86	38	0.0%	-1.86 [-5.51, 1.79]
Total (95% CI)			**226**			**220**	**100.0%**	**-0.03 [-0.07, 0.01]**

Mean Difference
IV, Random, 95% CI



Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 3.29$, df = 3 (P = 0.35); $I^2 = 9\%$
Test for overall effect: Z = 1.30 (P = 0.19)

Forest plot of duration of weaning

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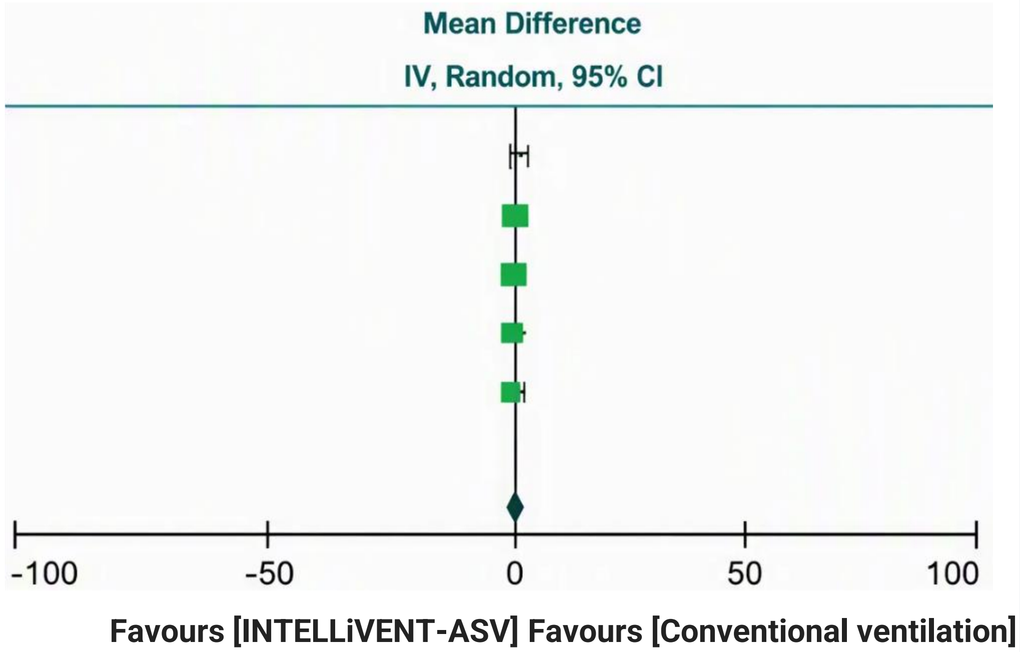
	INTELLiVENT-ASV			Conventional				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Arnal 2018	3.5	3.5	30	2.33	2.34	30	0.0%	1.17 [-0.34, 2.68]
Fot 2017	0.14	0.1	20	0.14	0.06	20	23.9%	0.00 [-0.05, 0.05]
Beijers 2014	0.14	0.05	51	0.15	0.12	47	40.0%	-0.01 [-0.05, 0.03]
Lellouche 2013	0.24	0.1	30	0.28	0.12	30	20.5%	-0.04 [-0.10, 0.02]
De Bie 2019	0.14	0.14	103	0.19	0.31	105	15.6%	-0.05 [-0.12, 0.02]
Total (95% CI)			**234**			**232**	**100.0%**	**-0.02 [-0.05, 0.01]**

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 4.56$, df = 4 (P = 0.34); $I^2 = 12\%$

Test for overall effect: Z = 1.42 (P = 0.16)



M Botta, et al. Expert Rev Respir Med. 2021 Nov;15(11):1403-1413

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追求卓越

DUAL CONTROL MODES

Pressure-regulated volume control (PRVC)

PRVC

▶ 提供預設的通氣量，以預設的呼吸速率及吸氣時間給予，同時提供吸氣期恆定的壓力，遞減的 flow rate，可以控制呼吸速率及 I/E ratio, 並在最低的 PIP 下提供預設的通氣量

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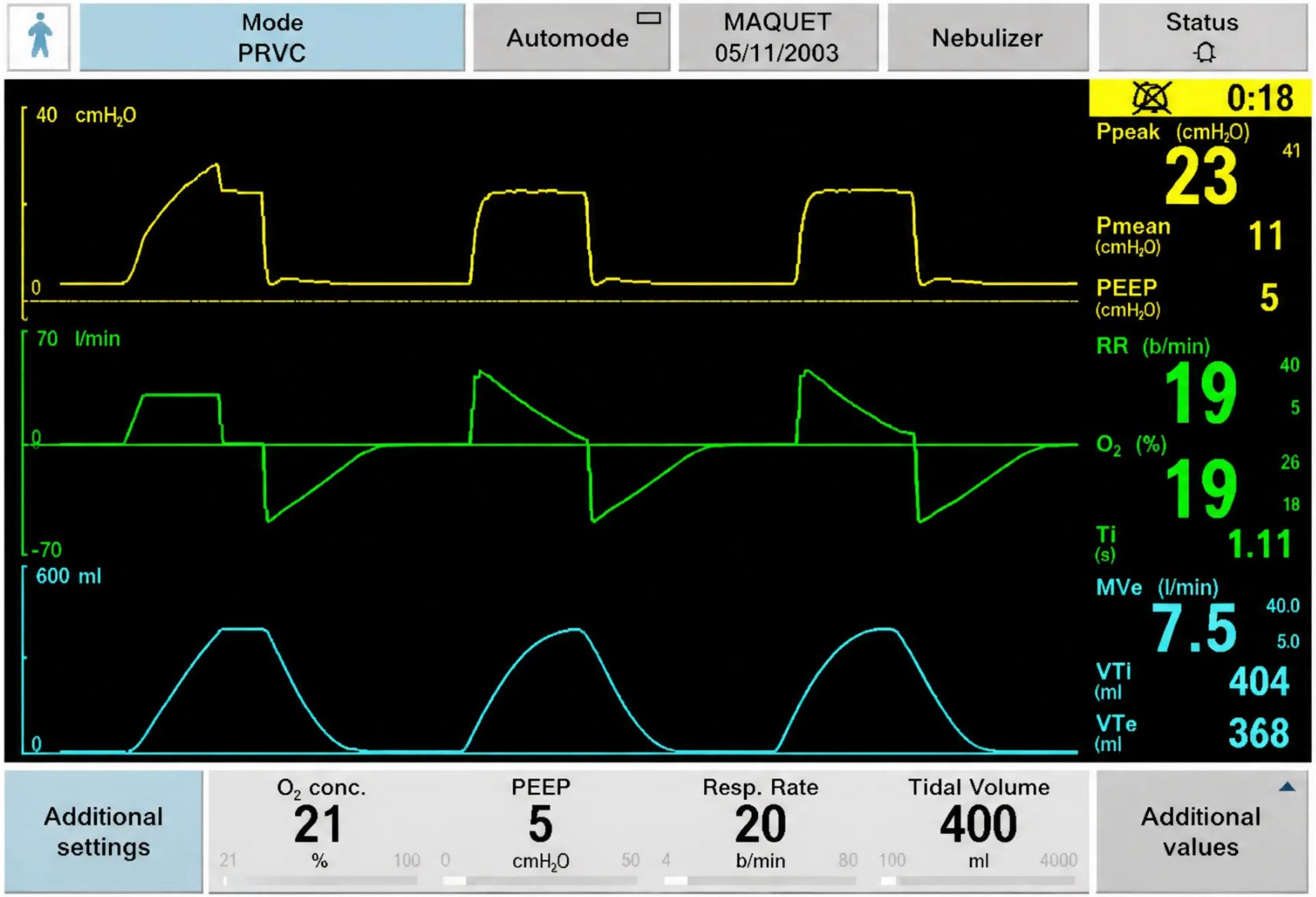

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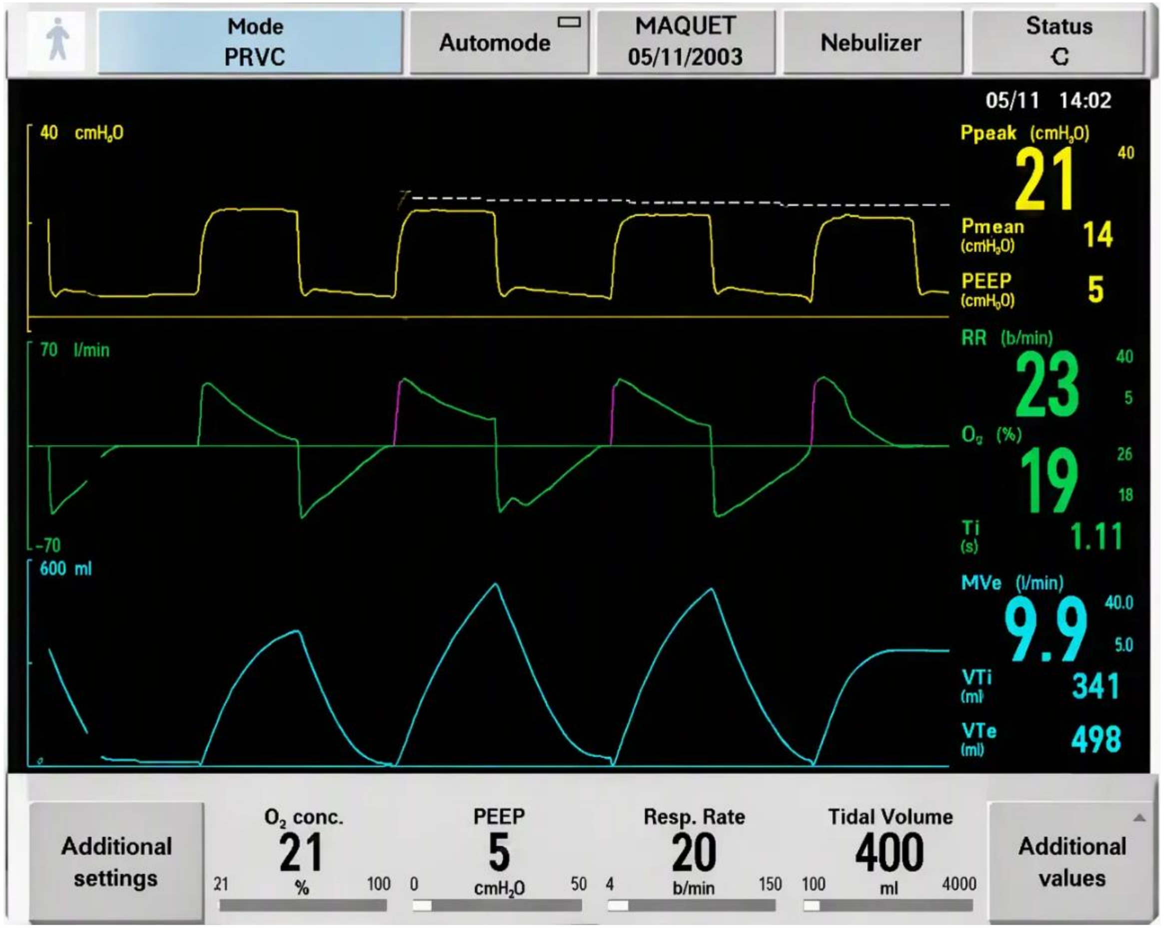
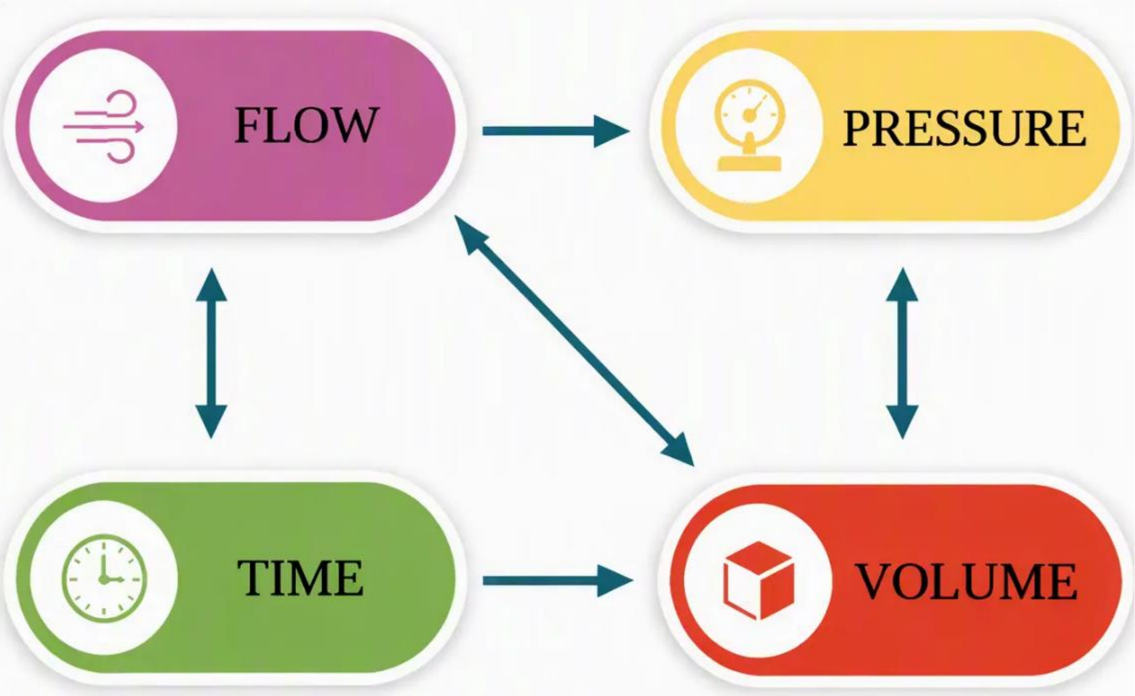
追求卓越


Mode
PRVC
Automode
MAQUET
05/11/2003
Nebulizer
Status
05/11 14:02
40 cmH2O
Ppeak (cmH2O)
21
Pmean (cmH2O)
14
PEEP (cmH2O)
5
70 l/min
-70
RR (b/min)
23
O2 (%)
19
Ti (s)
1.11
600 ml
MVe (l/min)
9.9
VTi (ml)
341
VTe (ml)
498
Additional settings
O2 conc.
21
%
PEEP
5
cmH2O
Resp. Rate
20
b/min
Tidal Volume
400
ml
Additional values


FLOW
PRESSURE
TIME
VOLUME

PC and VC

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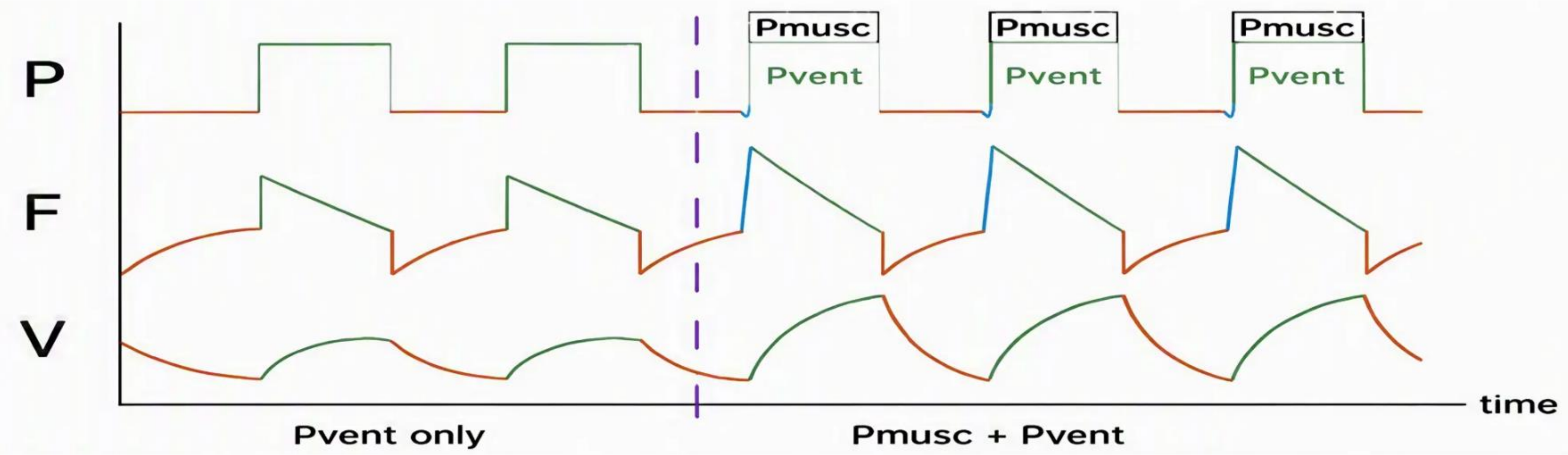

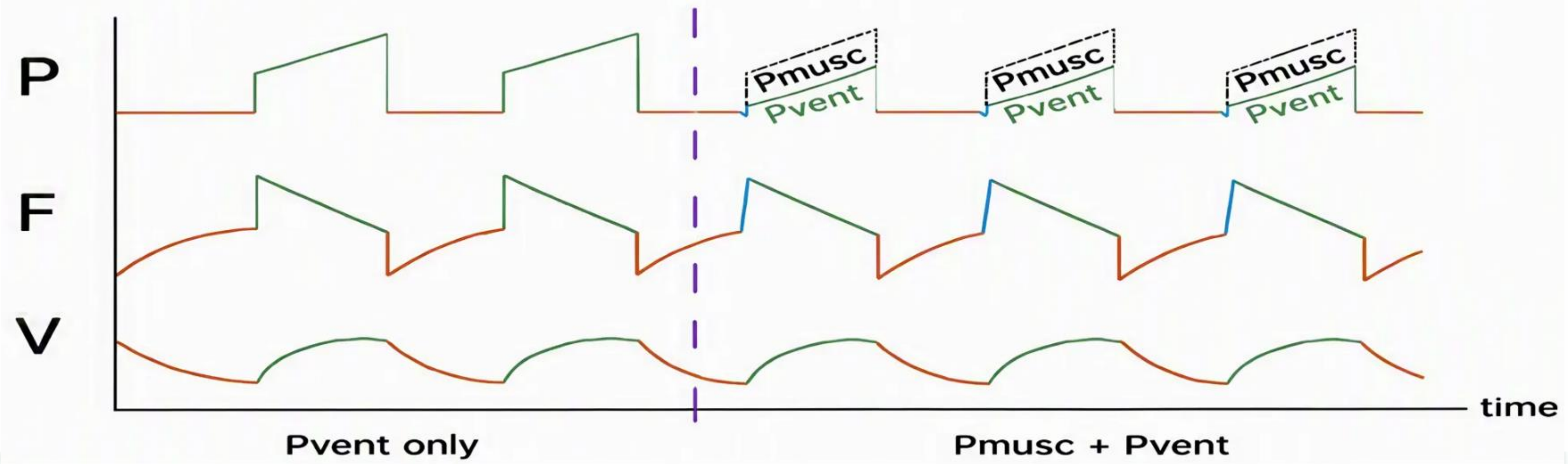

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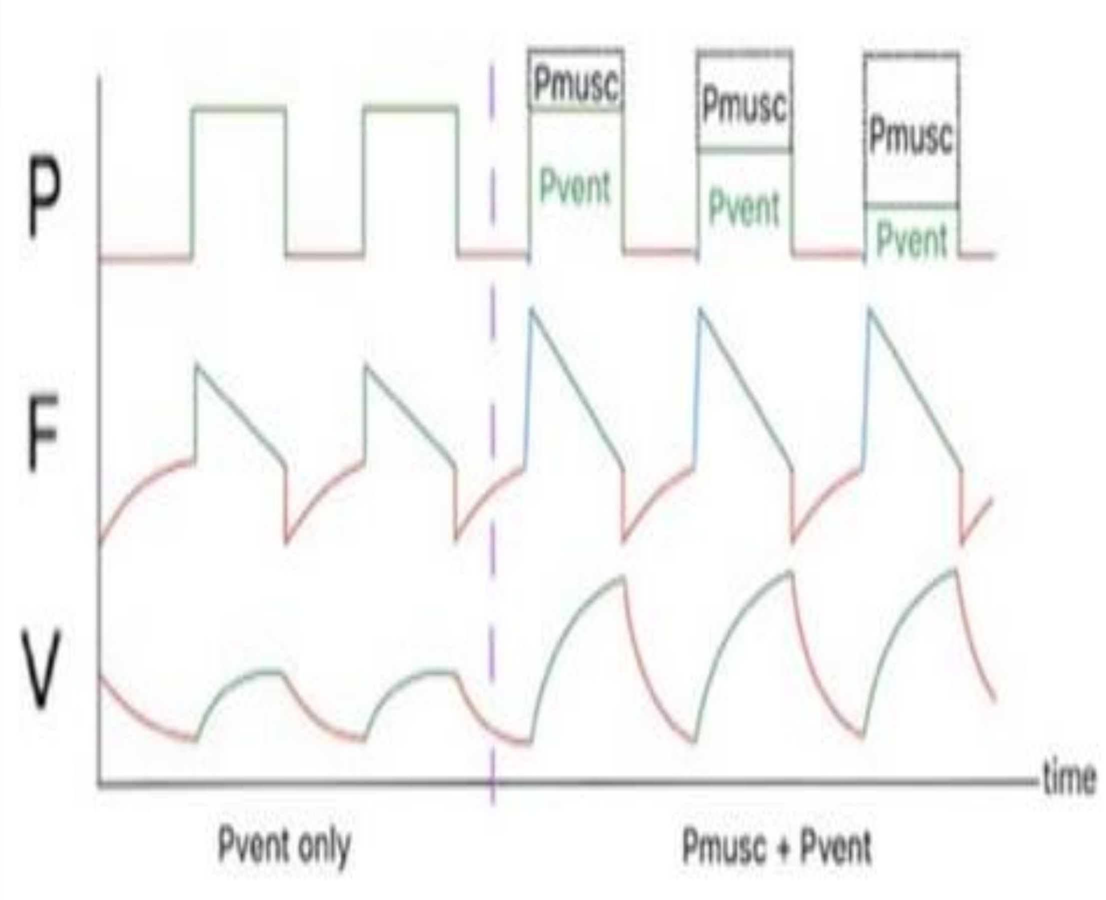
PRVC



P
F
V
Pmusc
Pvent
time
Pvent only
Pmusc + Pvent

MAQUET
PRVC
Automode
Admit patient
Status
Check battery status
06-11 11:04
Volume - Pressure
Flow - Volume
Ppeak 9
Pmean 6
PEEP 5
RR 23
O2 31
1.01
I:E 1:1.5
9.9
10.1
449
Close
O2 conc.
PEEP

> J Crit Care Med (Targu Mures). 2025 Oct 31;11(4):376-382. doi: 10.2478/jccm-2025-0043. eCollection 2025 Oct.

Evaluation of PRVC and SIMV ventilation techniques on hemodynamic metrics and arterial blood gases in ICU patients with multiple trauma: A randomized, triple-blind study

Majid Vatankhah Tarbebar 1, Saeed Kashani 1, Fatemeh Darsareh 1, Tayyebeh Zarei 1, Bibi Mona Razavi 1, Latifeh Farzanfar 2, Mehrdad Sayadinia 1, Pourya Adibi 1, Mansour Shabani 1, Mehrdad Malekshoar 1, Milad Mohammadi 1

P	in ICU patients with multiple trauma
I	PRVC and SIMV ventilation
C	hemodynamic metrics and arterial blood gases
O	Both groups stayed consistent regarding vital signs and other health indicators

OPEN AIRWAY MODES

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Airway Pressure Release Ventilation (APRV)

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APRV

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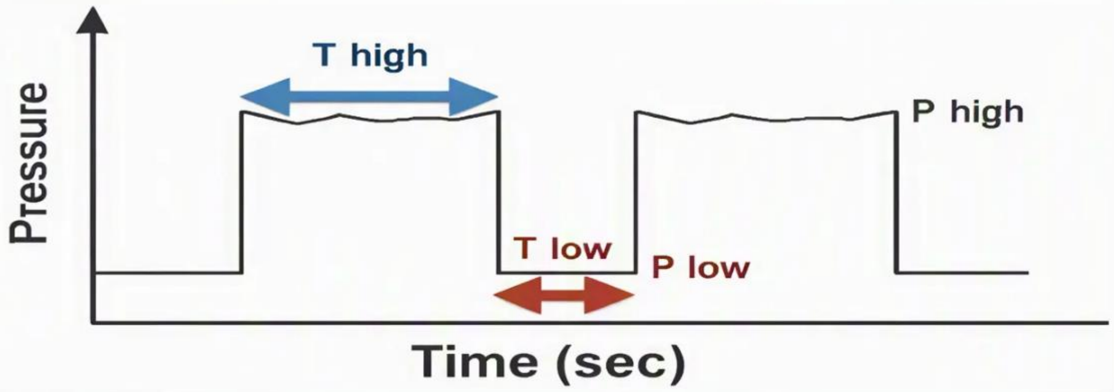
- ▶ an open lung strategy (maintain recruitment)
- ▶ is essentially 2 levels of CPAP.
- ▶ an inverse ratio (Long inspiratory time and short expiratory time).
- ▶ Improve oxygenation (⇧MAP) a mortality benefit has not been proven.
- ▶ an open dynamic expiratory valve that allows for spontaneous respirations both during the P high (inspiratory phase) and P low phases (expiratory phase).



Sumeet V Jain, ect. Intensive Care Med Exp. 2016 Dec;4(1);11.
S P Stawicki, ect. J Intensive Care Med. 2009 Jul-Aug;24(4);215-29.

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追求卓越

APRV initial setting

Items	Set
P high	VC (Set at P plat) or PC (Set at PIP) or 25~28 cmH_2O to target tidal volume 4~8 mL/kg IBW **Note: attempt to keep P high≤30 cmH2O or ≤ 35 cmH2O in obesity**
P low	0 - 5 cmH_2O
T high	4 - 8 sec (suggest 5 sec)
T low	0.3 – 0.8 sec (suggest 0.5 sec)
FiO_2	100% (attempt to wean <60%)
Respiratory Rate = # of releases (60 sec/ T high+ T low) ex: T high = 4.5 sec, T low = 0.5 sec , 12 of releases	

Zhou Y et al. Intensive Care Medicine 2017

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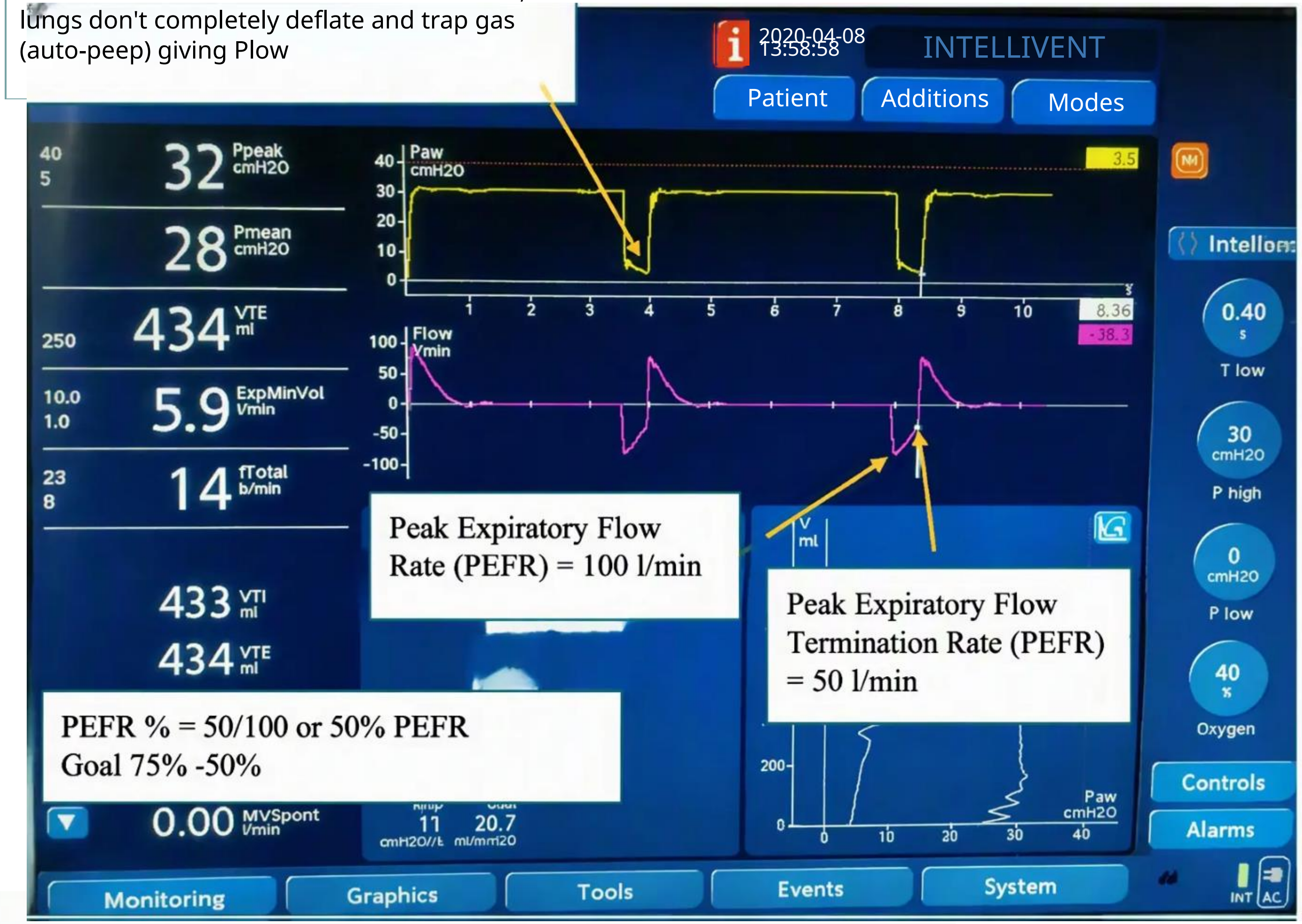
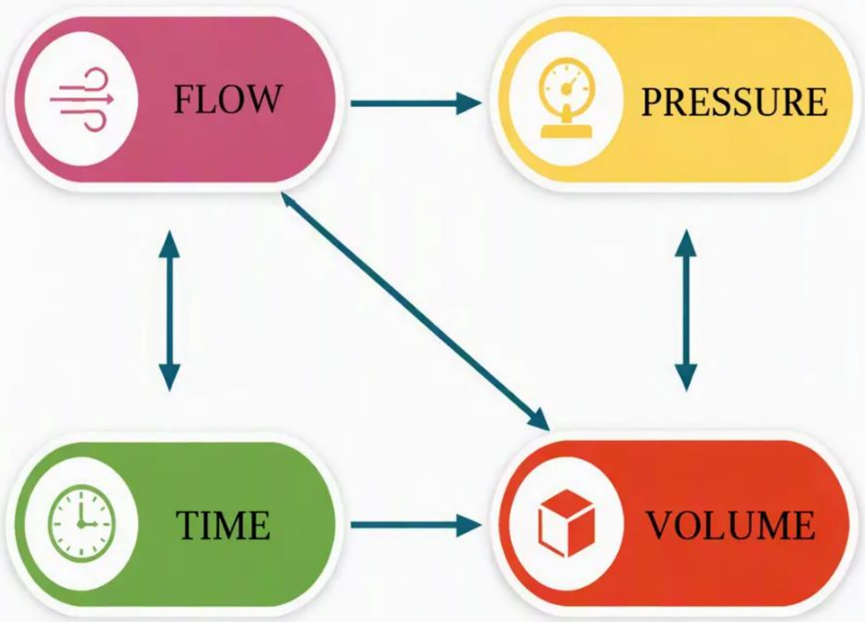
Plow set to zero however since Tlow is short, lungs don't completely deflate and trap gas (auto-peep) giving Plow



Peak Expiratory Flow Rate (PEFR) = 100 l/min

Peak Expiratory Flow Termination Rate (PEFR) = 50 l/min

PEFR % = 50/100 or 50% PEFR
Goal 75% -50%



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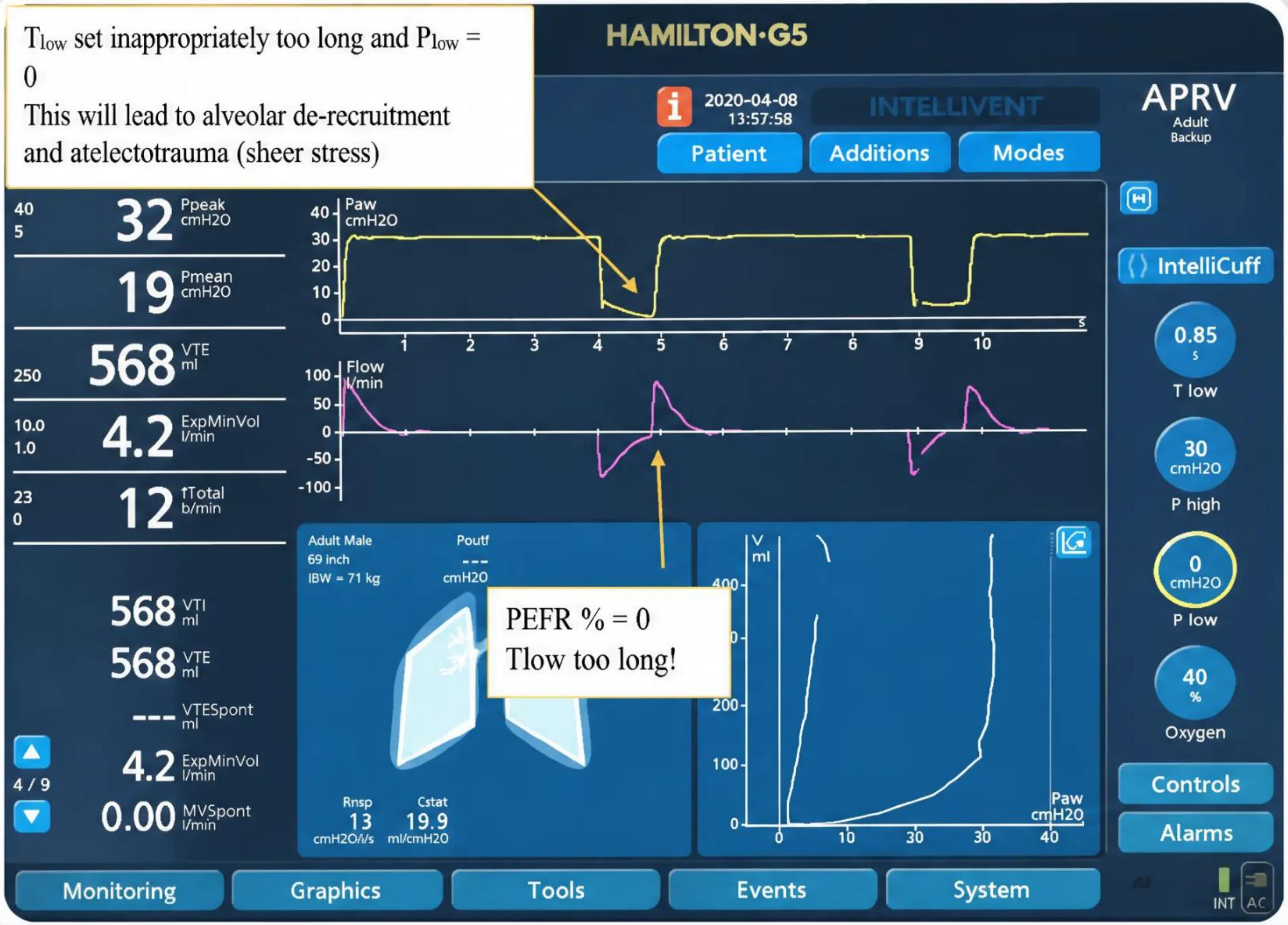
T_{low} set inappropriately too long and P_{low} = 0

This will lead to alveolar de-recruitment and atelectotrauma (sheer stress)



PEFR % = 0

Tlow too long!

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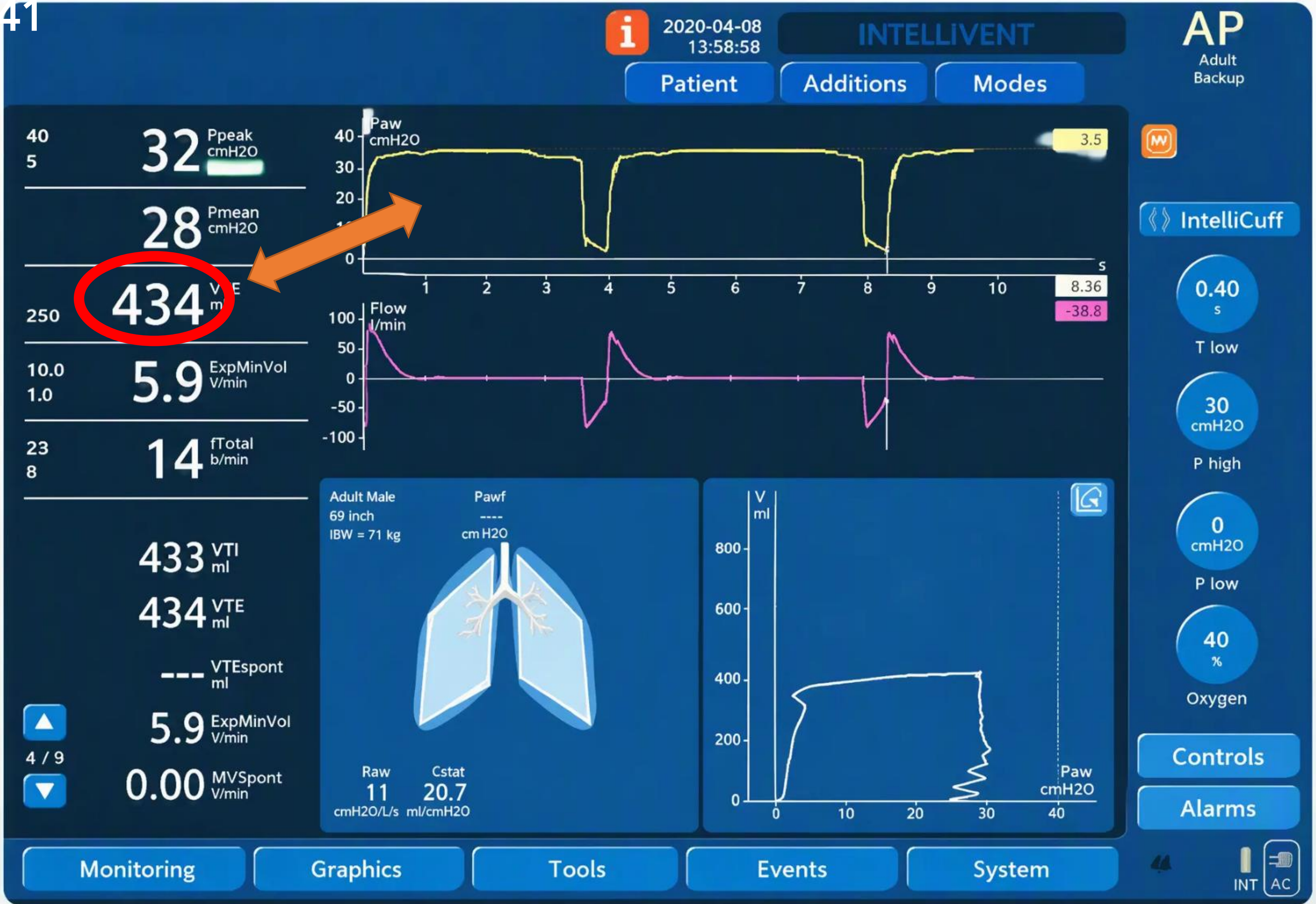
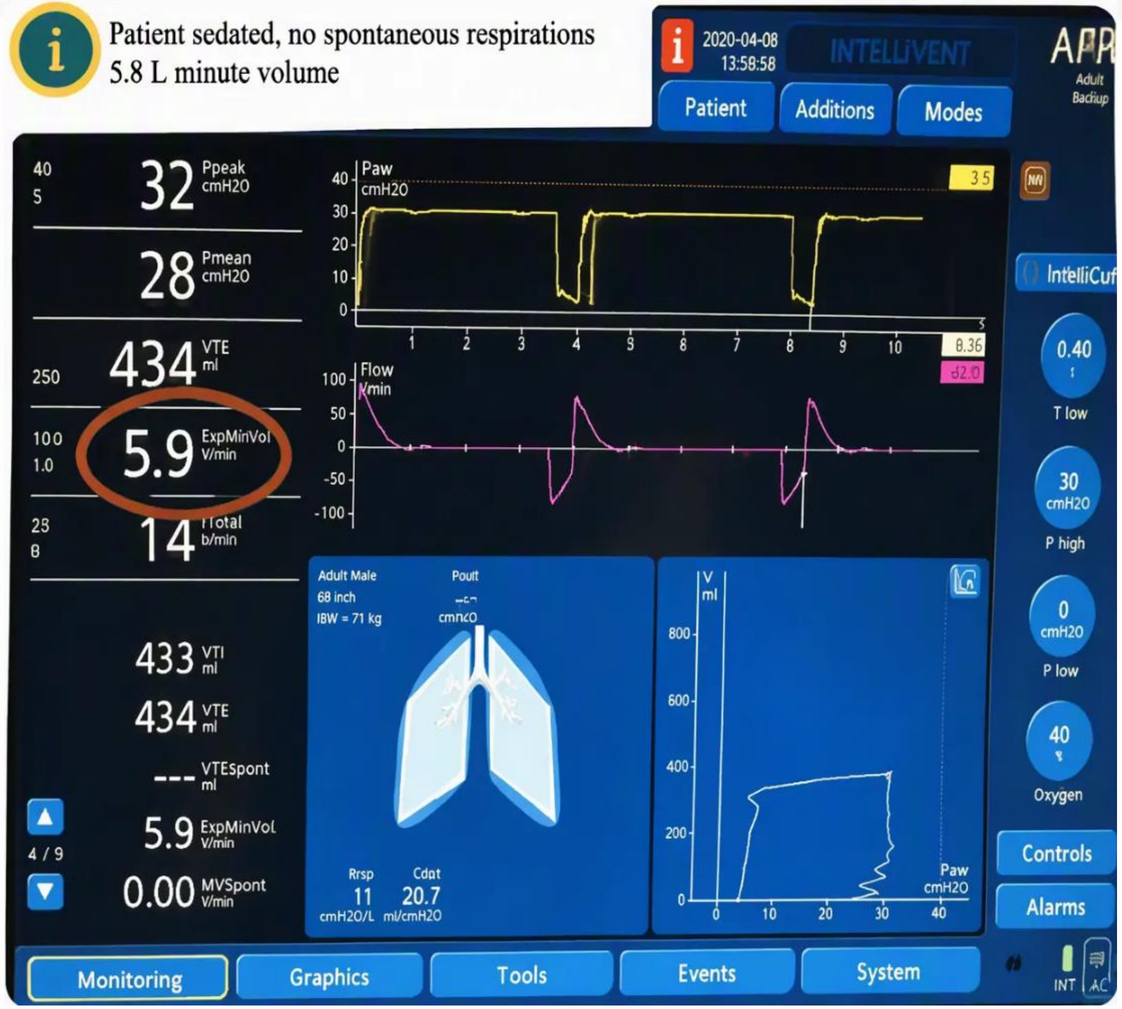
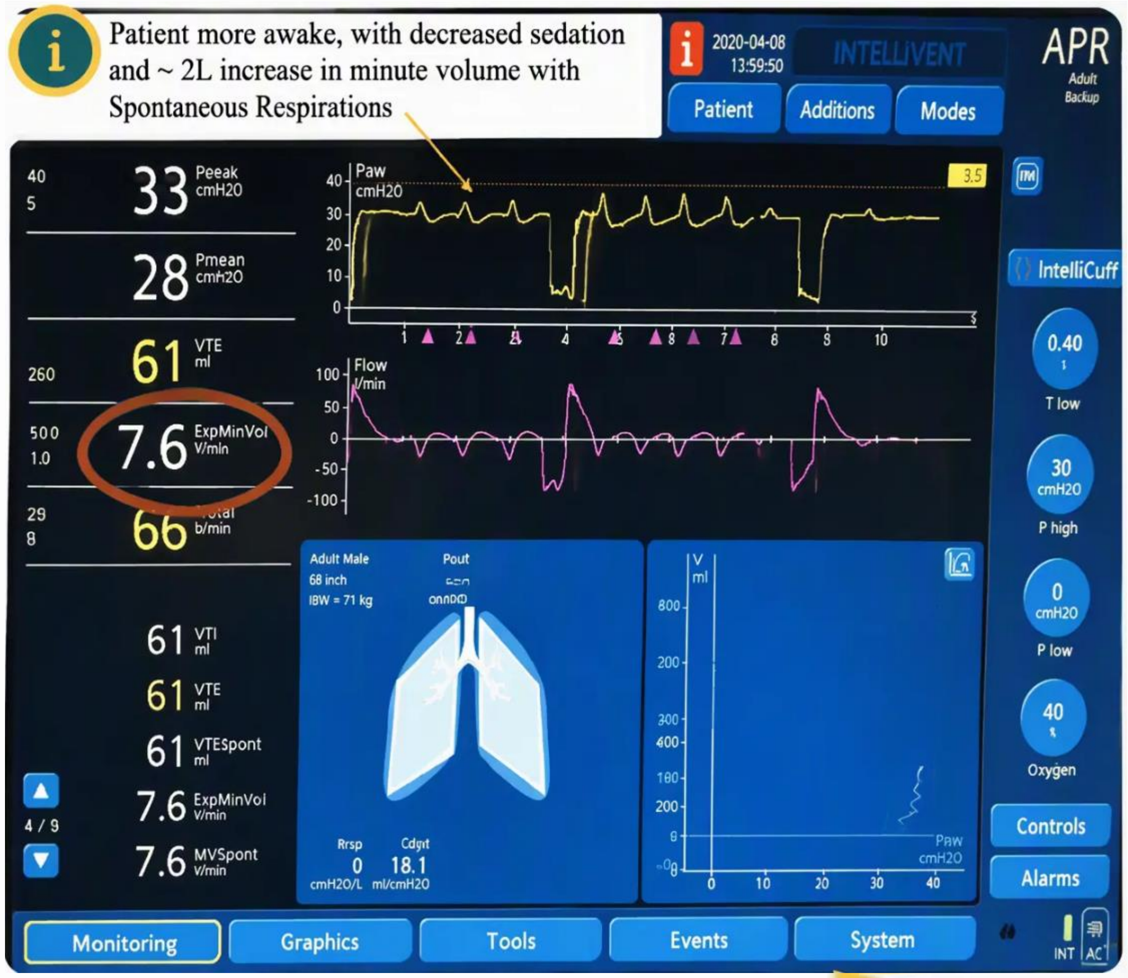


視病猶親
追求卓越





Zhou Y et al. Intensive Care Medicine 2017

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追求卓越

Adjusting APRV

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Oxygenation = FiO_2 and Mean Airway Pressure (MAP)

P high	▪ Increased 1-2 cmH_2O to target tidal volume(4 – 8 mL/kg IBW) ▪ Don't >30 cmH_2O or 35 cmH_2O (obesity) ▪ Determinant mean airway pressure (MAP) ▪ Main determinant tidal volume
T high	▪ Increased P high for longer time increasing MAP
T low	▪ Decreased to set PEFR 50-70%, Goal: trapped gas(auto- PEEP) and maintain a higher P low ▪ Too long can cause alveoli to de-recruit and hypoxemia as well as potential cause atelectotrama (sheer stress)

Ventilation = Minute Ventilation (tidal volume x Rate)

P high	▪ Increased and main determinant tidal volume
T low	▪ Increased to allow more time to exhale and remove CO_2
T high	▪ Decreased (if oxygenating well) as a shorter T high will allow more release

Spontaneous Respirations = If able, try to weaning sedation to allow more spontaneous breaths as this can significantly contribute to minute ventilation.

Zhou Y et al. Intensive Care Medicine 2017

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追求卓越

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Review

> Respir Res. 2024 Jan 18;25(1):37. doi: 10.1186/s12931-023-02615-y.

Time-Controlled Adaptive Ventilation (TCAV): a personalized strategy for lung protection

Hassan Al-Khalisy [1], Gary F Nieman [2], Michaela Kollisch-Singule [2], Penny Andrews [3], Luigi Camporota [4], Joseph Shiber [5], Toni Manougian [6], Joshua Satalin [7], Sarah Blair [2], Auyon Ghosh [2], Jacob Herrmann [8], David W Kaczka [8], Donald P Gaver [9], Jason H T Bates [10], Nader M Habashi [3]

視病猶親
追求卓越

Two potentially beneficial features of TCAV

1) the expiratory duration is personalized to a given patient's lung physiology, which promotes alveolar stabilization by halting the progressive collapse of alveoli, thereby minimizing the time for the reopened lung to collapse again in the next expiration.

2) an extended inspiratory phase at a fixed inflation pressure after alveolar stabilization gradually reopens a small amount of tissue with each breath.

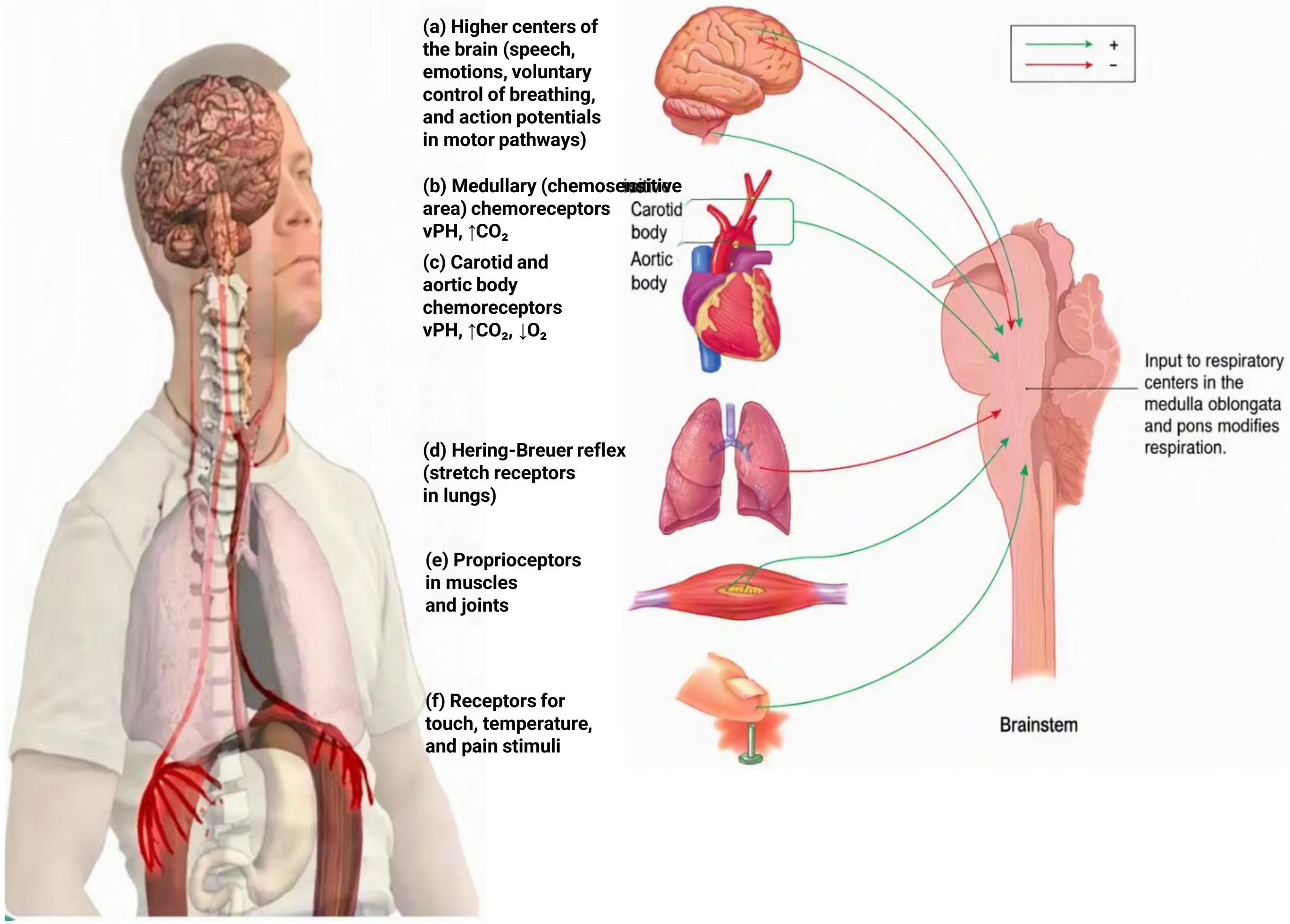
ADVANCED SPONTANEOUS MODES

臺北榮總

NEURALLY ADJUSTED VENTILATORY ASSIST(NAVA)

視病猶親
追求卓越

NAVA



Central nervous system

↓

Phrenic nerve

↓

Diaphragm excitation — Edi → **Neural triggering in NAVA**

↓

Diaphragm contraction — [Synchrony ↑]

↓

Chest wall and lung expansion

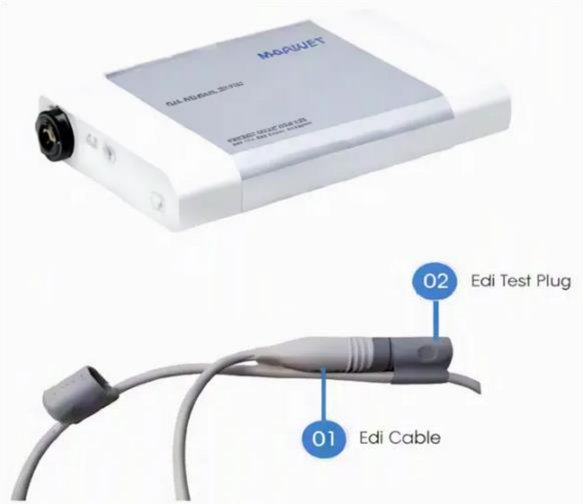
↓

Airway pressure, flow, and volume → **Conventional triggering**

使用Edi monitor或NAVA mode的準備

臺北榮總

Servo-i / Servo-u / Servo-n
with NAVA mode

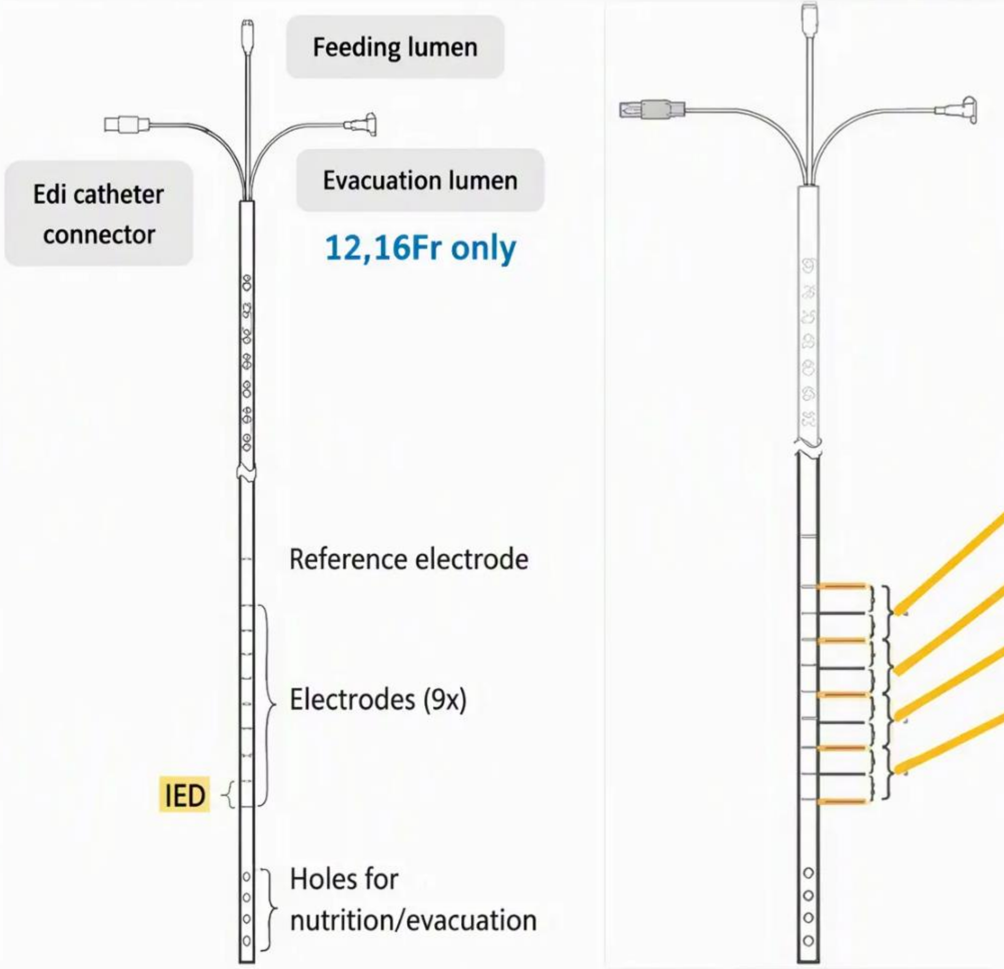


Edi module+ cable

Edi catheter

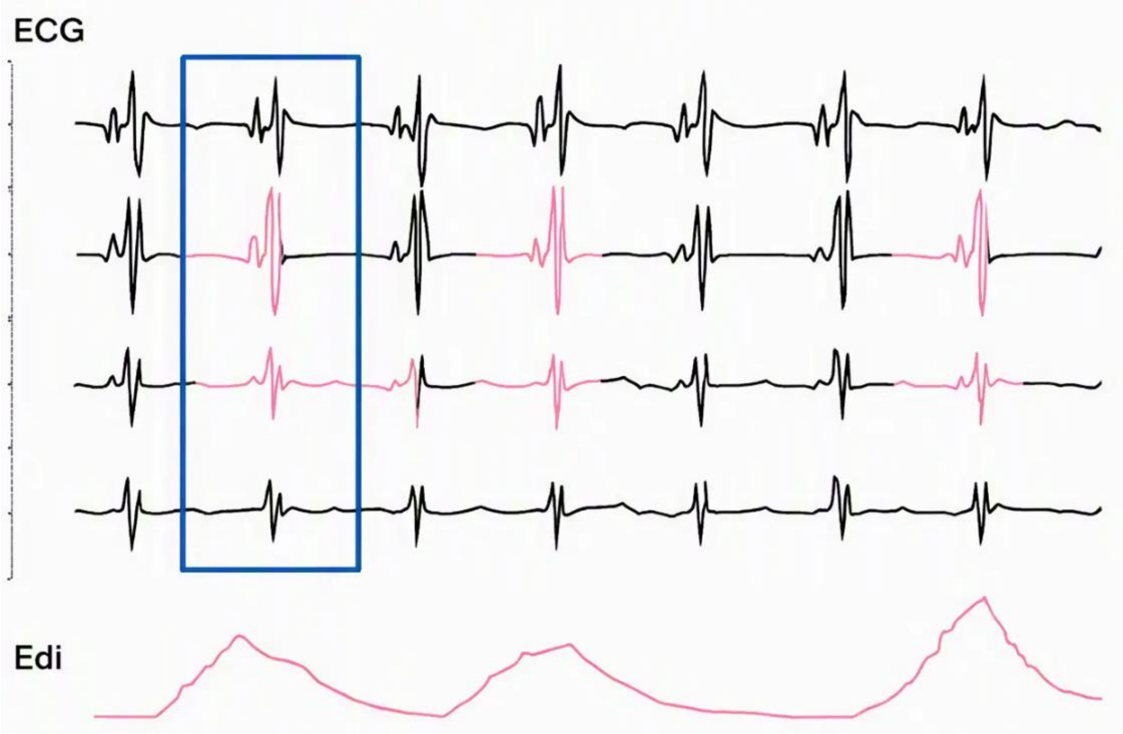
視病猶親
追求卓越

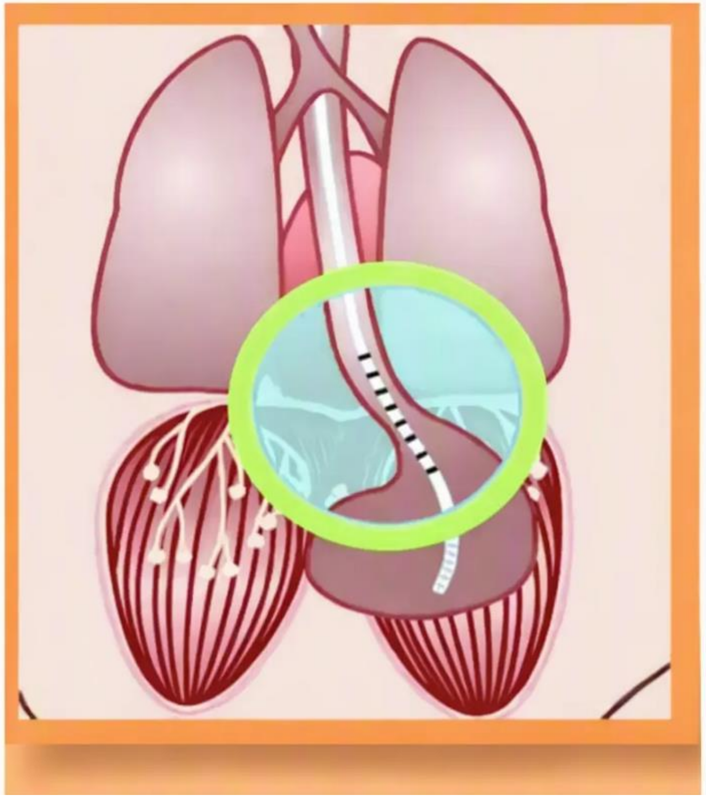
評估Edi catheter置放深度 - 電極對應波型



評估Edi catheter置放深度 (正確位置)

臺北榮總





杏昌生技 呼吸睡眠部

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追求卓越

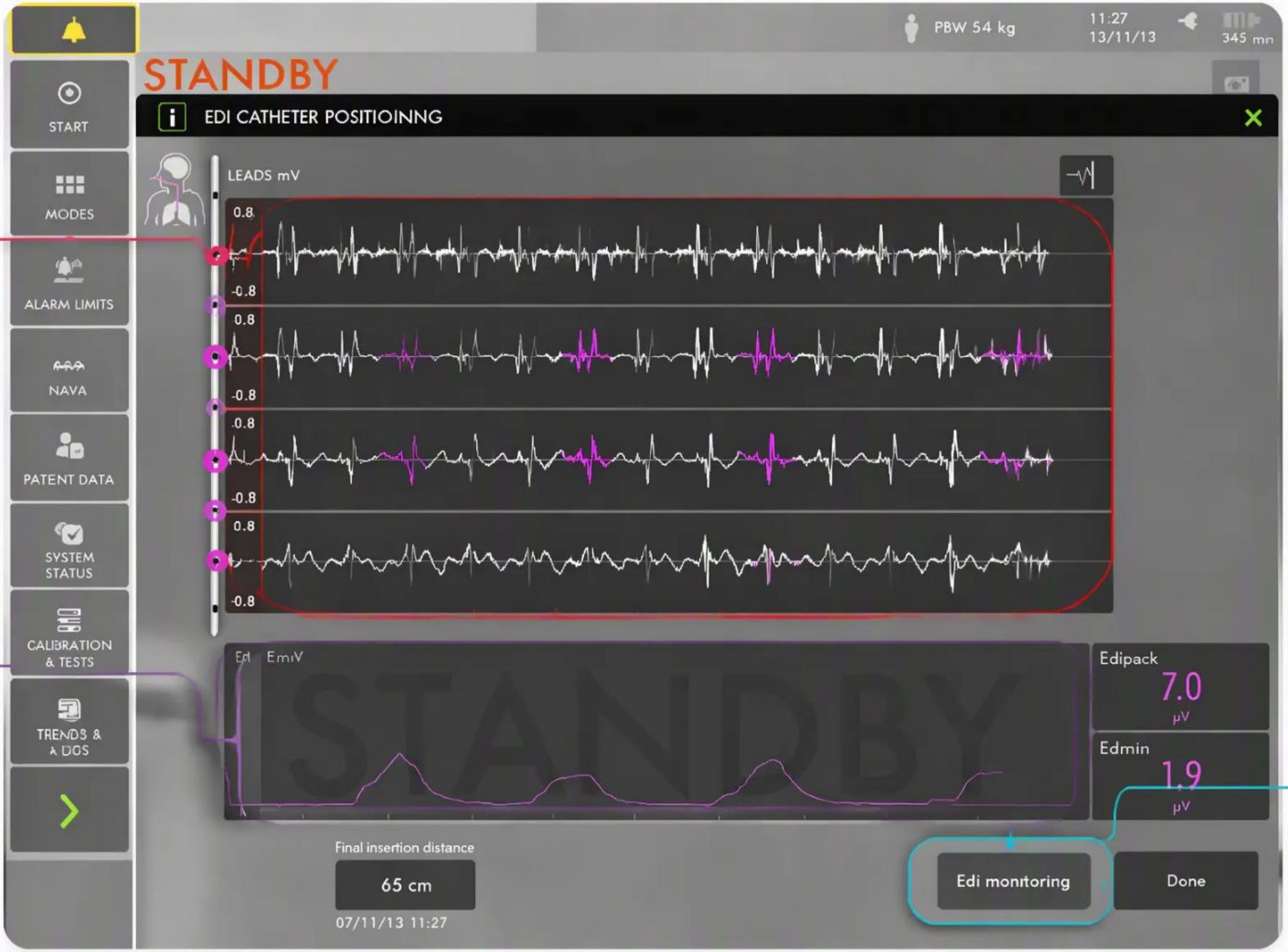
四大要素

臺北榮總

Esophageal ECG

Edi signal

Shortcut to Edi monitoring window



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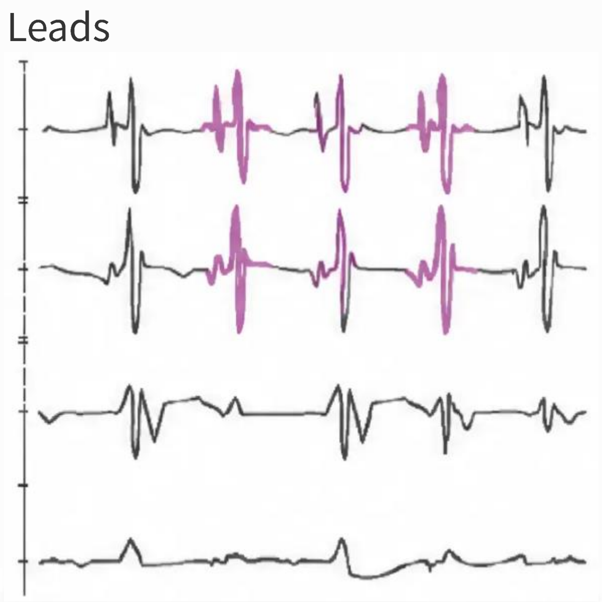
追求卓越

Edi catheter position

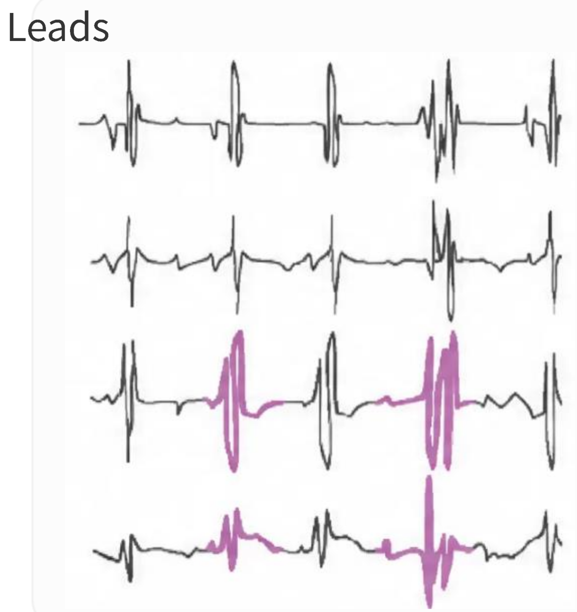
Reposion Edi Catheter

第一層代表離心臟最近，第四層最遠，故波形振幅
由上至下應由大到小



Too deep

Pull out slightly



Too shallow

Insert carefully further

NAVA mode parameters

臺北榮總

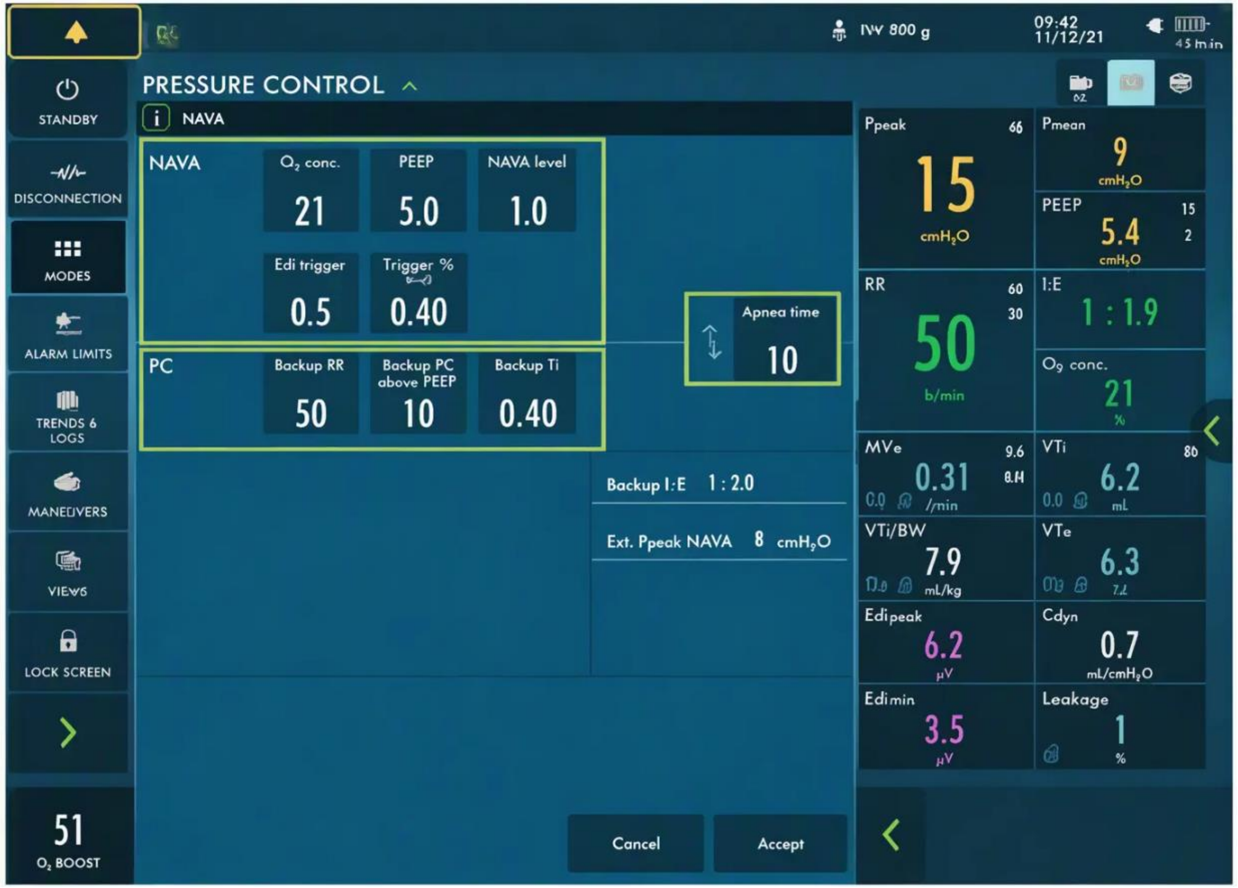
- NAVA
  - O2 conc.
  - PEEP
  - NAVA level
  - Edi trigger
  - Pneumatic trigger(Flow or P)

Back ventilation: PC mode

Apnea time

Upper pressure limit

*PIP最高給予壓力為Upper pressure limit -5 cmH2O



視病猶親 追求卓越

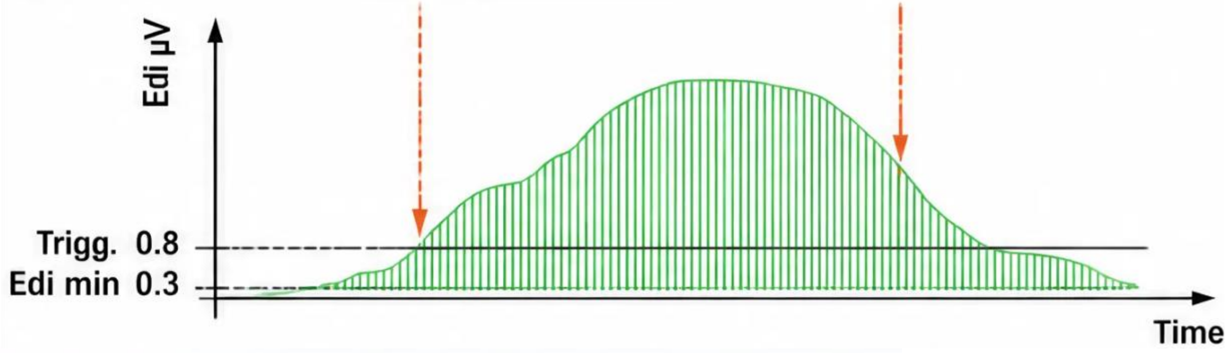
Edi Parameters (橫隔膜電位)

Edi Peak and Edi min

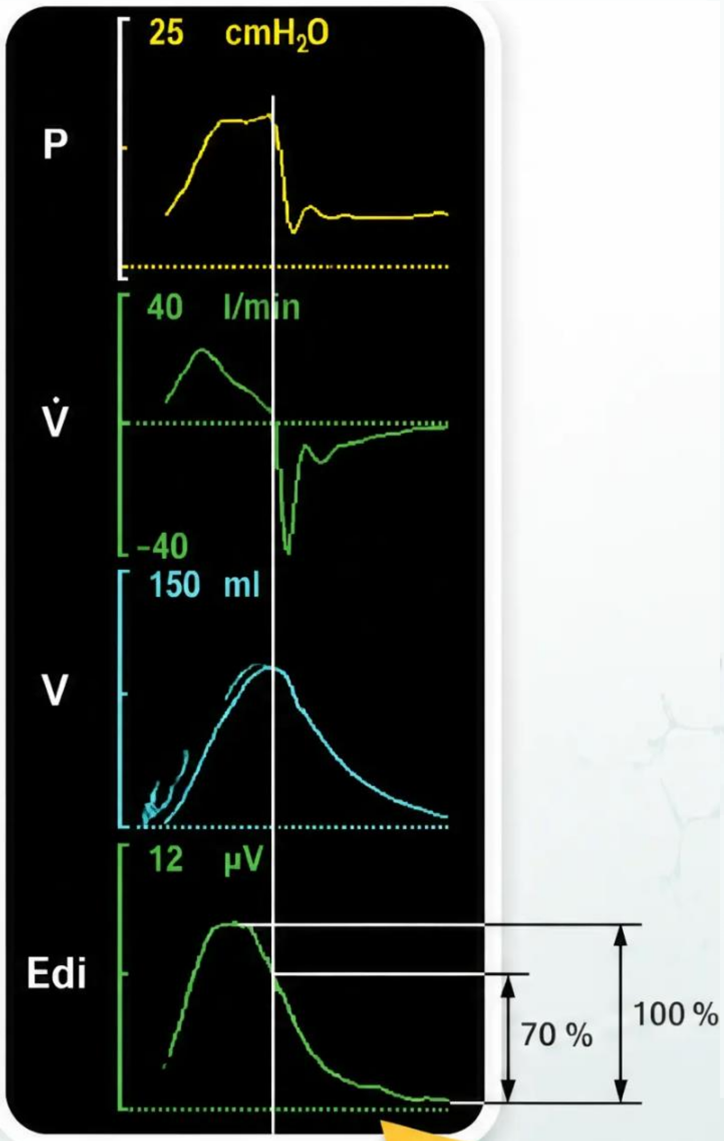
- **Edi peak(μV):**
  Reflects the work the diaphragm has to perform for each breath.
  橫隔肌吸氣時最大驅力
- **Edi min(μV) :**
  Shows the baseline level the diaphragm is resting at between the contractions.
  橫隔肌放鬆時的電位

Edi Trigger
Edimin為基礎往上加
Ex : set 0.5uV, Edimin 0.3uV
0.5+0.3 = 0.8uV, 達0.8uV時開始吸氣期

當Edipeak降至70%
轉吐氣期



NAVA detects Edi signal 62.5 times/sec



視病猶親
追求卓越

NAVA level (cmH_2O / μV)

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▶ NAVA level 即為 每單位 μV 的 Edi 電位呼吸器 給予多少 壓力輔助 cmH_2O

▶ 單位： cmH_2O / μV

PIP = NAVA level x (Edi peak –Edi min) + PEEP

cmH_2O

cmH_2O/μV

ΔEdi = 病患的呼吸驅力

μV

視病猶親

追求卓越

When to adjust NAVA level?

Increase

- Signs of ↑ WOB
- Consistently low Vt
- Consistently high RR
- Any time patient appears to need more assistance

Decrease

- Consistently high Vt
- Consistently low RR
- Any time patient appears to be receiving too much assistance

Advantages of NAVA

- Desaturation index was lower.
- Mean Edi and PIP were lower.

Oda A, et al. Neurally adjusted ventilatory assist in ventilated very preterm infants: A crossover study. Pediatr Pulmonol. 2021 Dec;56(12):3857-3862.

- Lower extubation failure rates.
- Shorter duration of MV.
- Overall length of stay was lower.

Shetty S, et al. Neurally Adjusted Ventilatory Assist in Very Prematurely Born Infants with Evolving/Established Bronchopulmonary Dysplasia. AJP Rep. 2021 Nov 22;11(4):e127-e131.

臺北榮總

特性	傳統模式 (Conventional)	新型模式 (Novel)
控制核心	固定流速、容積或壓力	動態回饋、自適應計算
臨床人員	必須頻繁抽血、手動微調參數	設定目標，由機器自動優化路徑
主要目的	維持基本的氣體交換	肺保護策略、提高舒適度、加速呼吸器脫離

Maintenance

臺北榮總

保養等級	人員	項目
一級保養	臨床 RT 維修 RT	終期消毒、換管、過濾棉片更換、吐氣 filter 更換、使用前校正、flow sensor 更換校正
二級保養	維修 RT	執行內部校正、吐氣模組更換、外部零件更換
三級保養	工程師	故障維修

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追求卓越

Troubleshooting

Alarm	Ventilator	Patient
High pressure	• High pressure limit 設定不佳 • Tube kinking • 外接 flow 吸藥	• Cough、有痰 • Lung compliance poor • Bronchospasm
Low pressure or disconnect alarm	• 管路脫落 • 吐氣端沒接好 • 管路有漏氣	• demand 大 • Cuff 破
High volume	• High volume limit 設定不佳 • 外接 flow 吸藥	• demand 大
Low volume	• 管路有漏氣	• Lung compliance poor • Bronchospasm
Show error code	• 吐氣模組及 flow sensor 更換 卸機工程師維修	

視病猶親
追求卓越

Future Perspectives

臺北榮總

▶ 智慧化與 AI 應用：呼吸器學習輔助脫離呼吸器預測與自動化參數調整。

▶ 開發挑戰：可攜式、低成本急性呼吸器的設計發展。

視病猶親
追求卓越

ENDING SLIDE

THANK YOU FOR YOUR ATTENTION!