Physiology and Setting of MV

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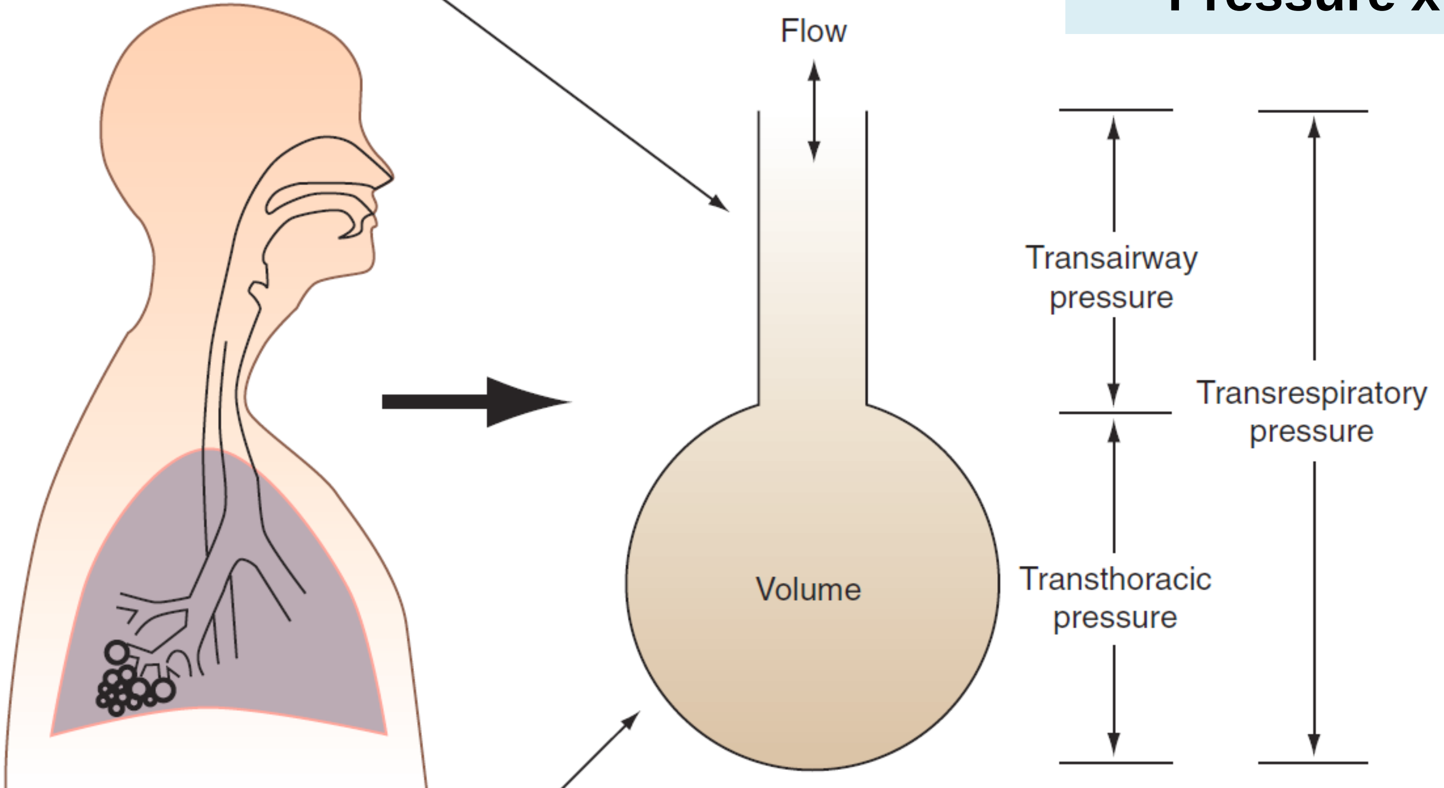
8:30-9:20 12 July 2020

Work of Breathing
Pressure x Volume

$$\text{Resistance} = \frac{\Delta\ \text{Transairway pressure}}{\Delta\ \text{Flow}}$$

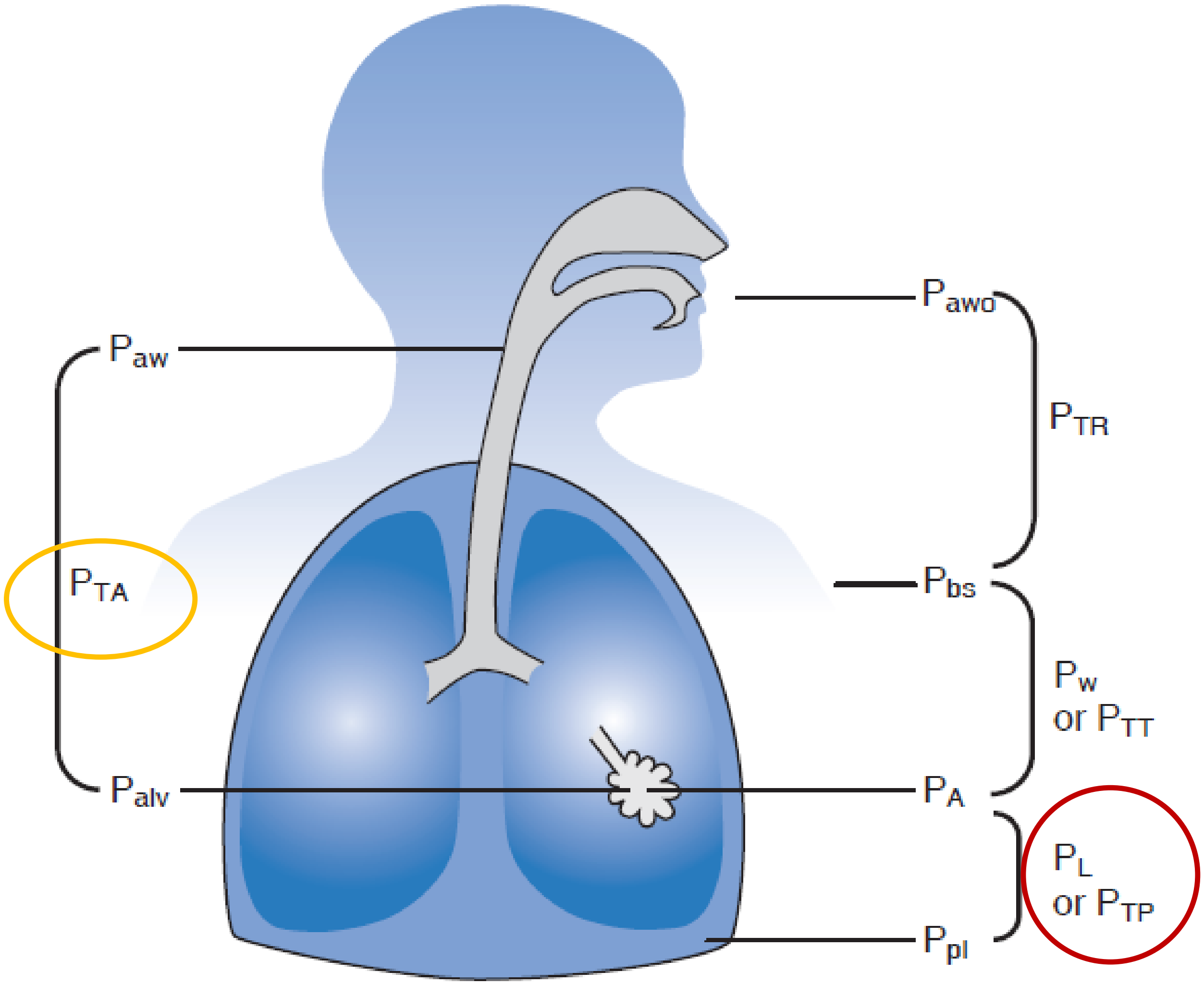


$$\text{Compliance} = \frac{\Delta\ \text{Volume}}{\Delta\ \text{Transthoracic pressure}}$$

$$\text{Elastance} = \frac{\Delta\ \text{Transthoracic pressure}}{\Delta\ \text{Volume}}$$

Equation of Motion for the Respiratory System

$$\text{Pvent} + \text{Pmuscles} = \text{elastance} \times \text{volume} + \text{resistance} \times \text{flow}$$



P_{awo} - Mouth or airway opening pressure

P_{alv} - Alveolar pressure

P_{pl} - Intrapleural pressure

P_{bs} - Body surface pressure

P_{aw} - Airway pressure (= P_{awo})

P_L or P_{TP} = Transpulmonary pressure ($P_L = P_{alv} - P_{pl}$)

P_w or P_{TT} = Transthoracic pressure ($P_{alv} - P_{bs}$)

P_{TA} = Transairway pressure ($P_{aw} - P_{alv}$)

P_{TR} = Transrespiratory pressure ($P_{awo} - P_{bs}$)

Pilbeam's mechanical ventilation

Spontaneous Inspiration

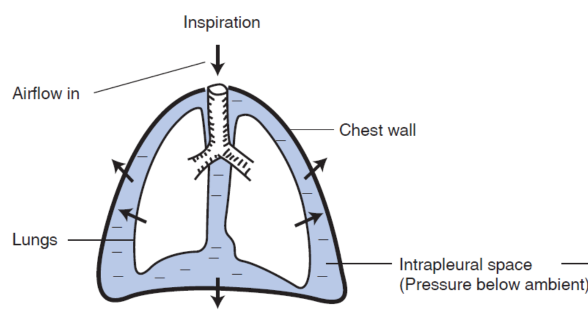
Volume Change

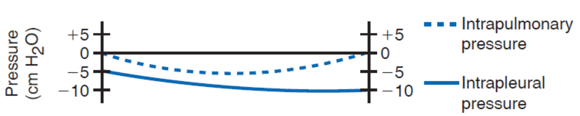
↓

Pressure Difference

↓

Gas Flow



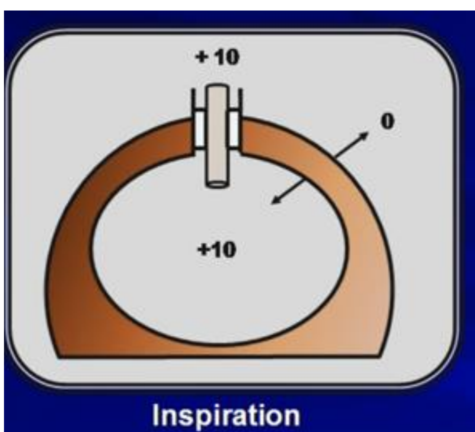


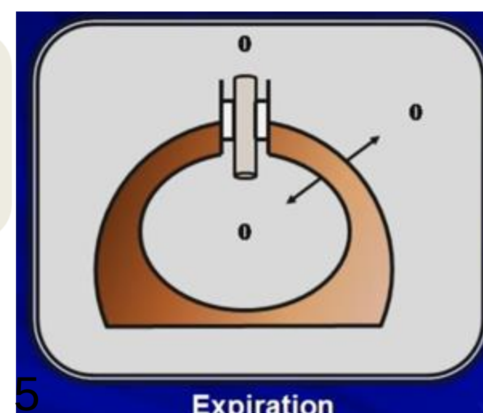
Mechanical Ventilation

Pressure Difference

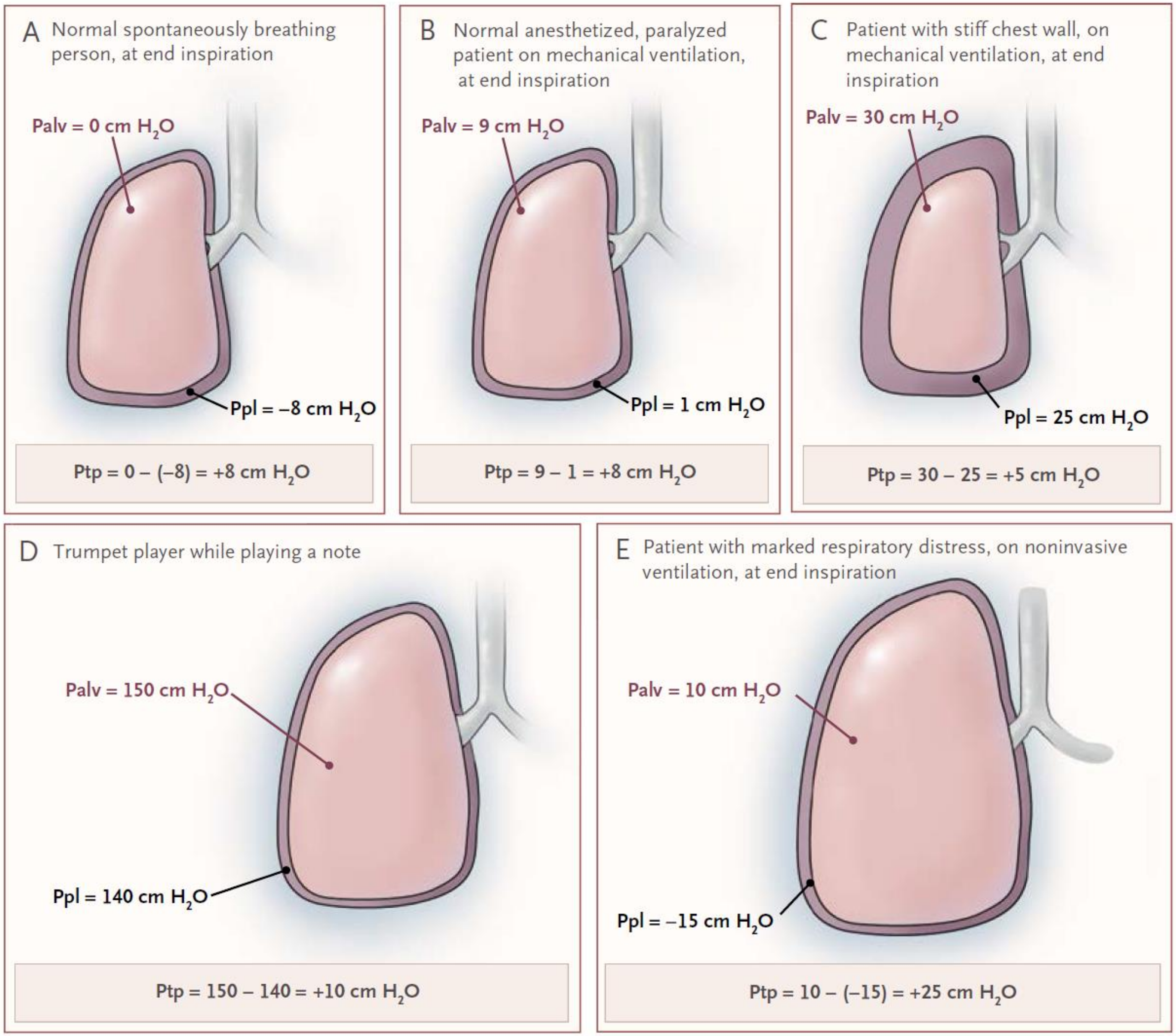
Gas Flow

Volume Change



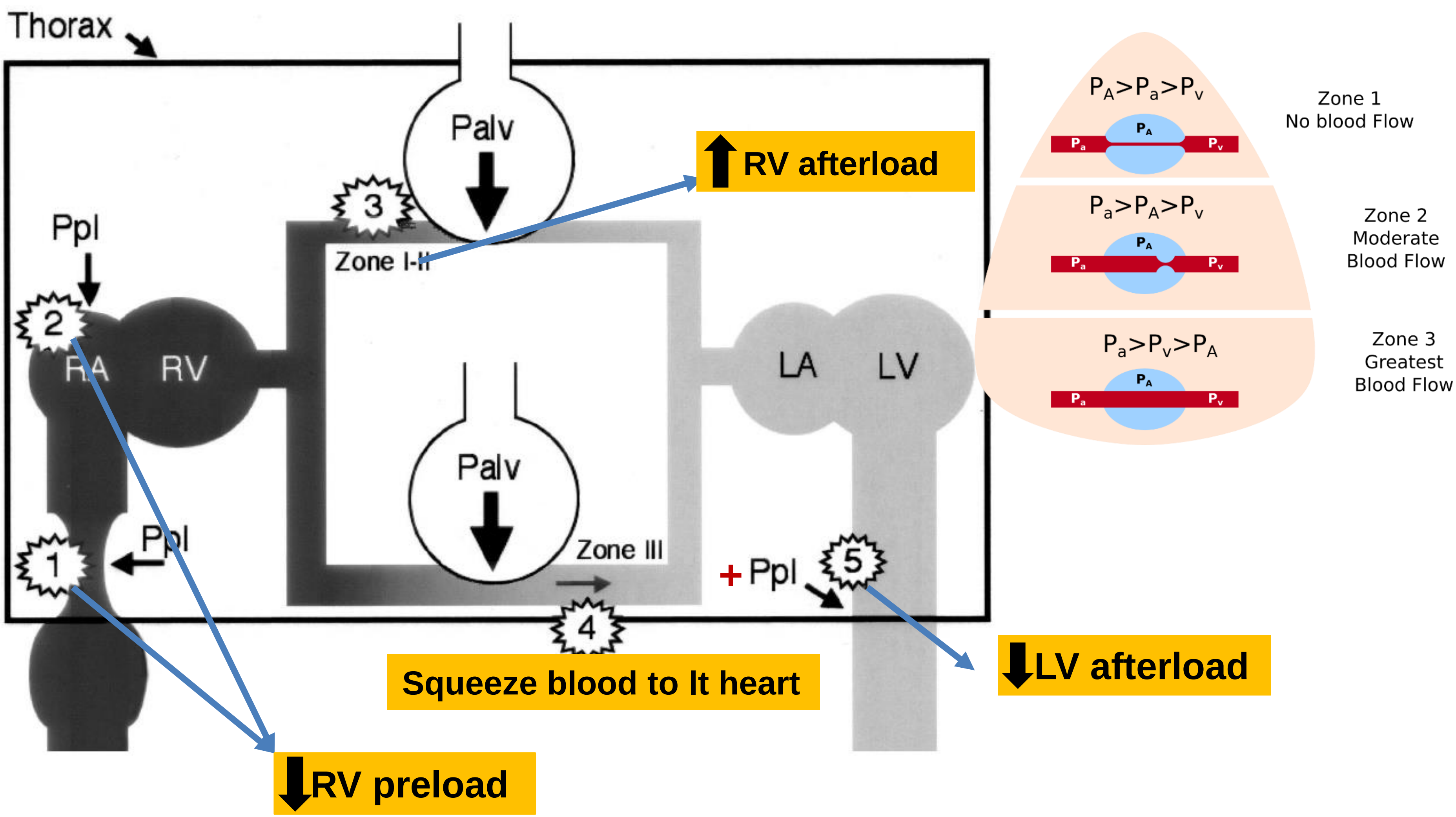


Transpulmonary pressure = Alveolar pressure – Pleural pressure



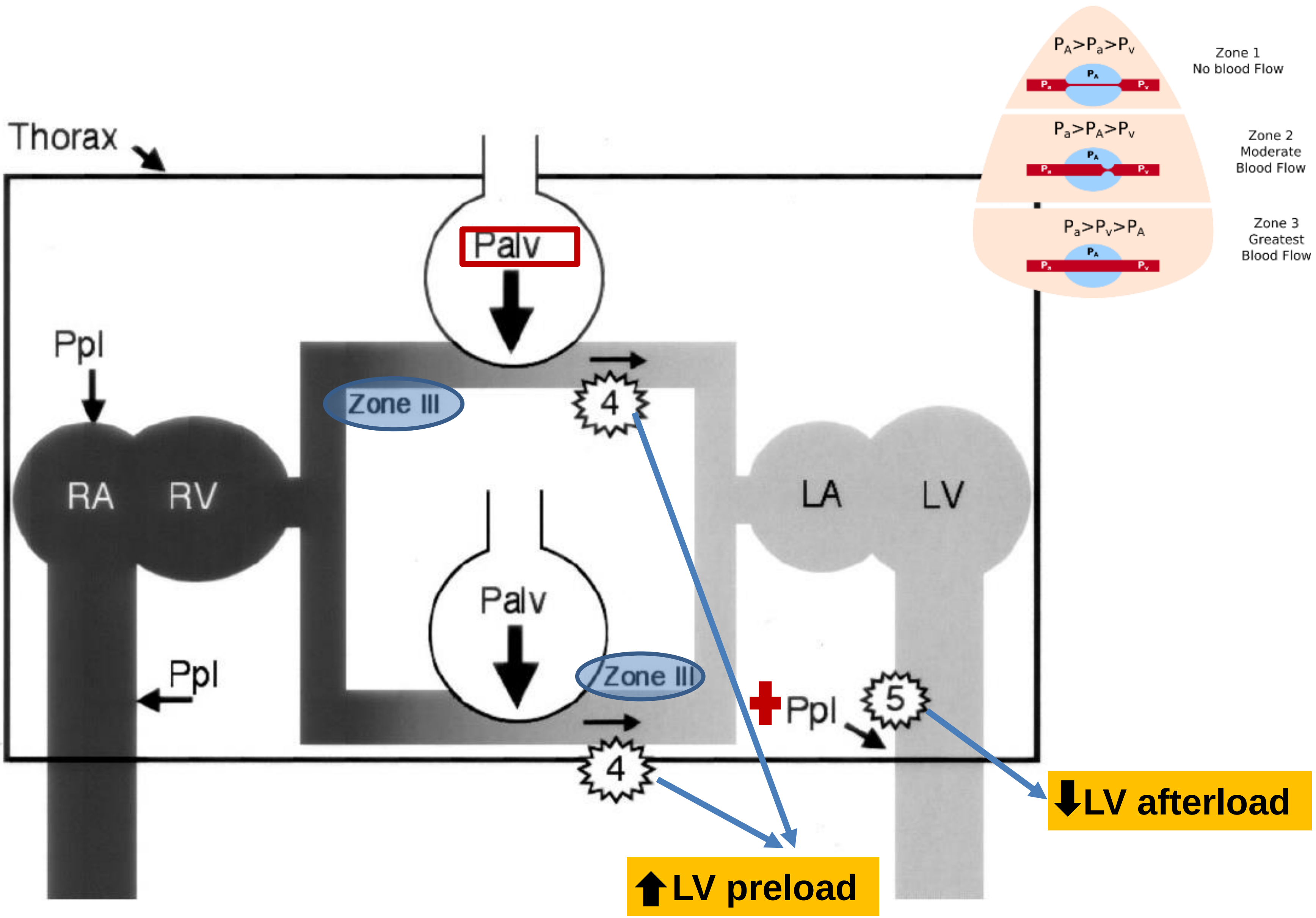
NEJM 2013; 369: 2126-2136

Physiologic effects of MV in hypovolemic conditions



Anesthesiology 2005;103:419-28

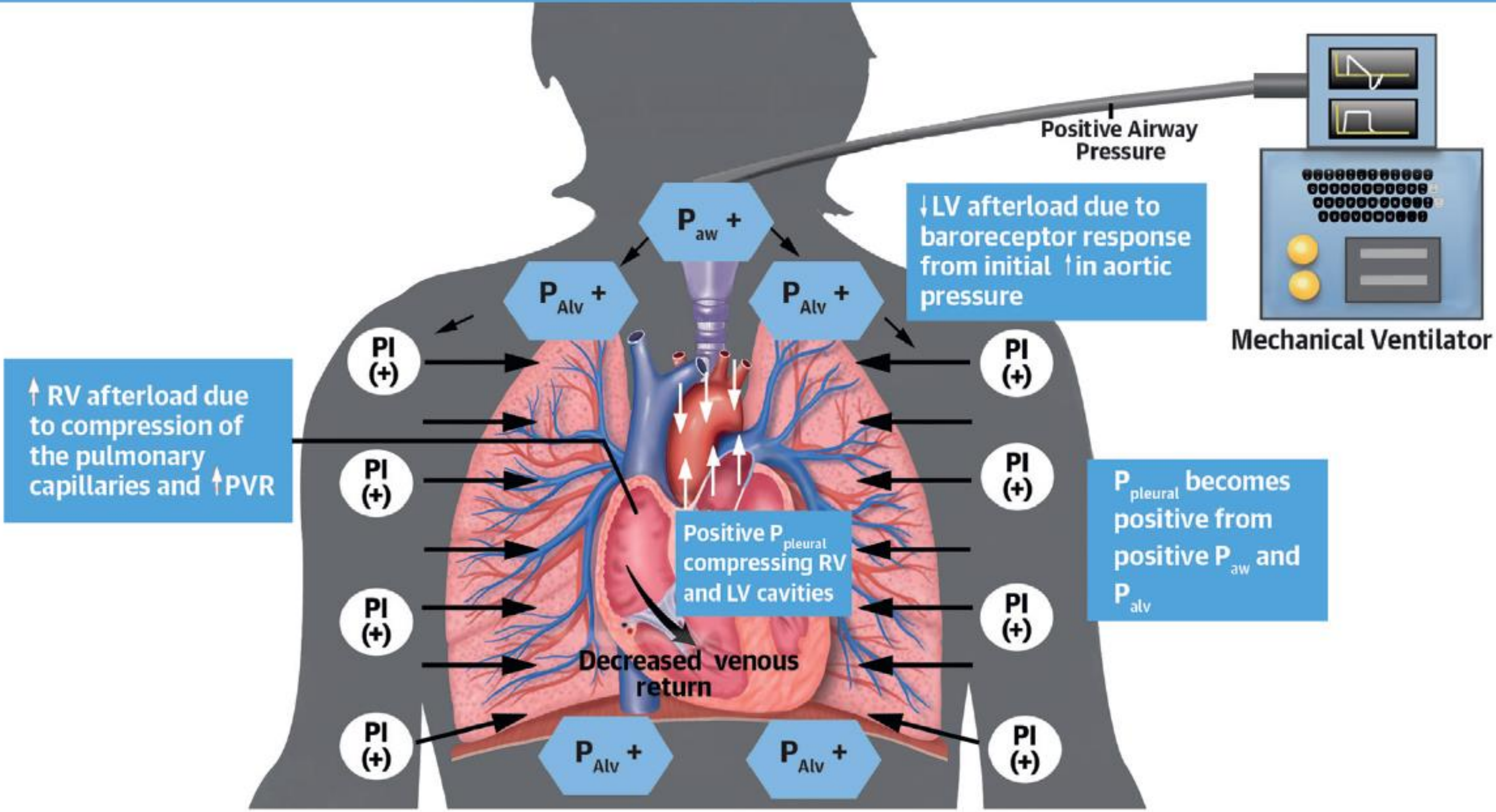
Physiologic effects of MV in hypervolemic conditions



Anesthesiology 2005;103:419-28

A. Postive Pressure Ventilation

P_{aw}, P_{alv} and $P_{pleural}$ Become Positive



Summary of Effects: $+P_{aw}$ → $+P_{alv}$ → $P_{pleural}$ → Compression of RV and pulmonary vessels → ↓Venous return, ↑RV afterload and ↓LV afterload by baroreceptor reflex

Potential physiologic effect of PEEP on ventricular function and cardiac output

Right Ventricle

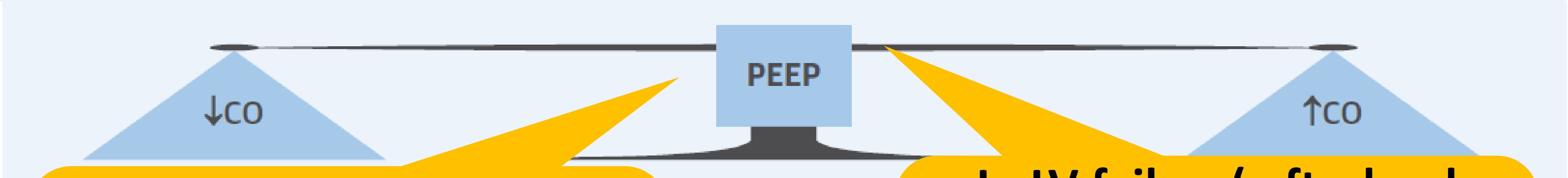
- ⬇ Right ventricular (RV) venous return
- ⬆ Pulmonary vascular resistance due to vascular compression
- ⬆ RV dilation → left shift in septum
- ⬆ Compensatory increase in systemic vascular resistance

- ⬇ Hypoxia mediated pulmonary vasoconstriction

Left Ventricle

- ⬇ Preload due to lower RV output
- ⬇ Stroke volume due to interventricular dependence

- ⬇ Left ventricular (LV) afterload
- ⬇ LV preload and LV dilatation
- ⬇ Myocardial oxygen demand
- ⬆ Pressure gradient from thorax to periphery
- ⬆ Hydrostatic displacement of alveolar edema



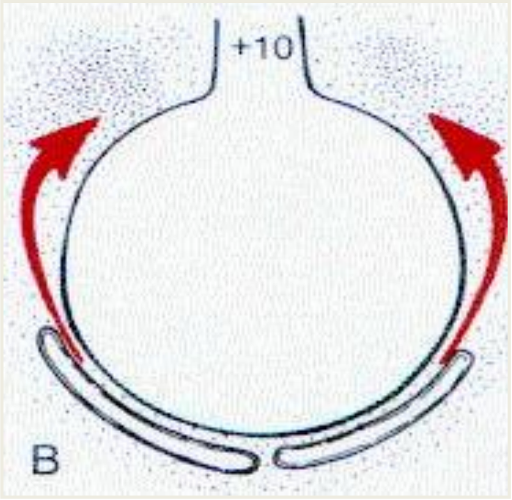
In RV failure(preload dependent) , moderate to high PEEP (5-15 cmH$_2$O) may decrease RV CO

In LV failure(afterload dependent),moderate to high PEEP(10-15 cmH$_2$O) may increase CO

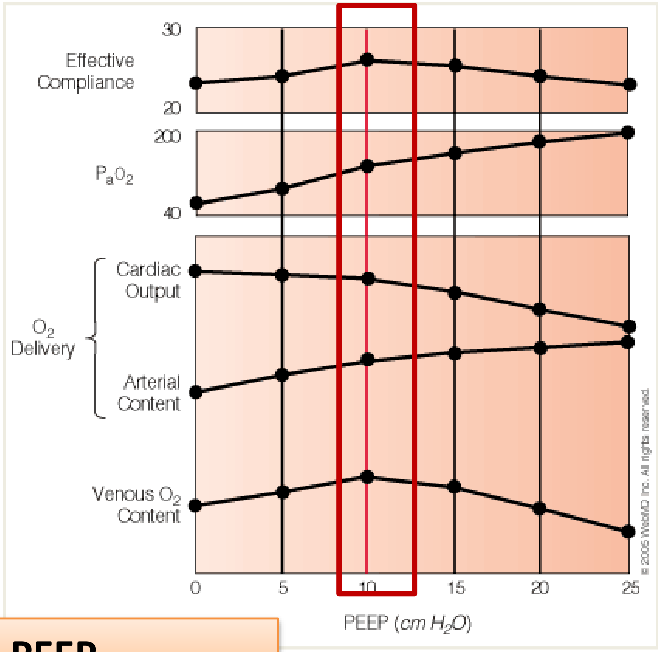
J Am Coll Cardiol 2018;72:1532-53

PEEP Effect

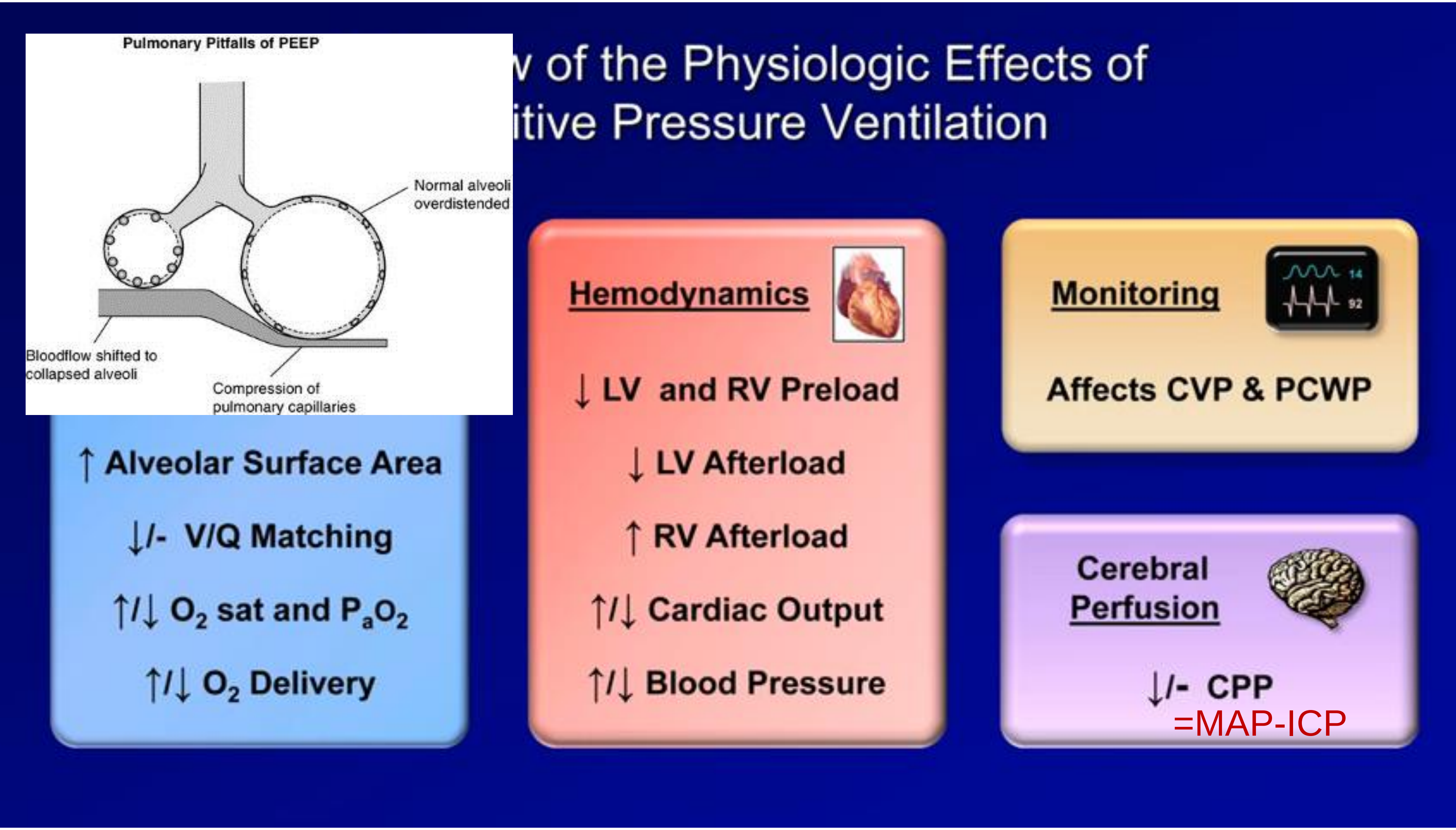
- **Increases FRC**
  - Prevents progressive atelectasis and intrapulmonary shunting
  - Prevents repetitive opening/closing (injury)
- **Recruits collapsed alveoli and improves V/Q matching**
  - Resolves intrapulmonary shunting
  - Improves compliance
- **Enables maintenance of adequate P_aO_2 at a safe FiO_2 level**
- **Disadvantages**
  - Increases intrathoracic pressure.
  - Barotrauma
  - Decrease cardiac output



Optimal PEEP



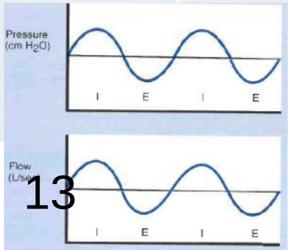
Oxygen delivery (DO_2), not PaO_2, should be used to assess optimal PEEP.



Strong medicine

Classification of MV

Type	Example	Tracheal intubation
Negative-pressure ventilators	• Iron lung • Chest cuirass	-
Positive-pressure ventilators	• Invasive positive pressure ventilator **(IPPV)** - PB 840 - Servo-I - Hamilton G5	+
	• Non-invasive positive pressure ventilator (**NIPPV** or BIPAP) • Continue positive pressure ventilation (CPAP) • High-flow nasal cannula (HFNC)	-
positive-/negative-pressure ventilators	• high-frequency oscillators (HFO)	+



Iron lung

Cuirass

Fig. 1-1. *Typical equipment available for respiratory failure in 1952: an iron lung (left) and a Kifa cuirass (right). (Image of child in iron lung reproduced courtesy of the WHO Global Polio Eradication Initiative. Image of adult reproduced from Lassen HCA (ed). Management of Life-threatening Poliomyelitis. Edinburgh: E & S Livingstone, 1956.)*

Component of Ventilator

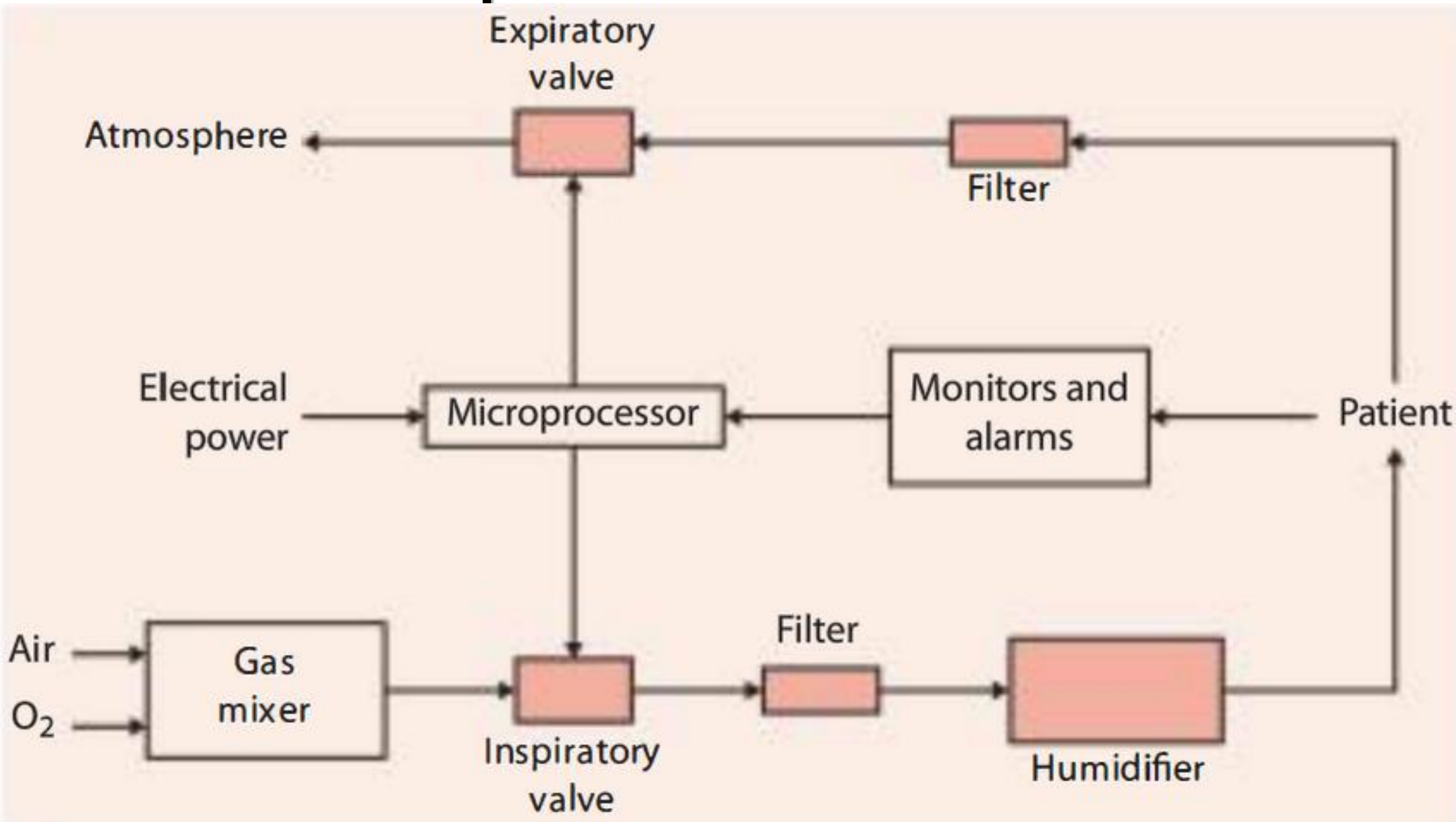
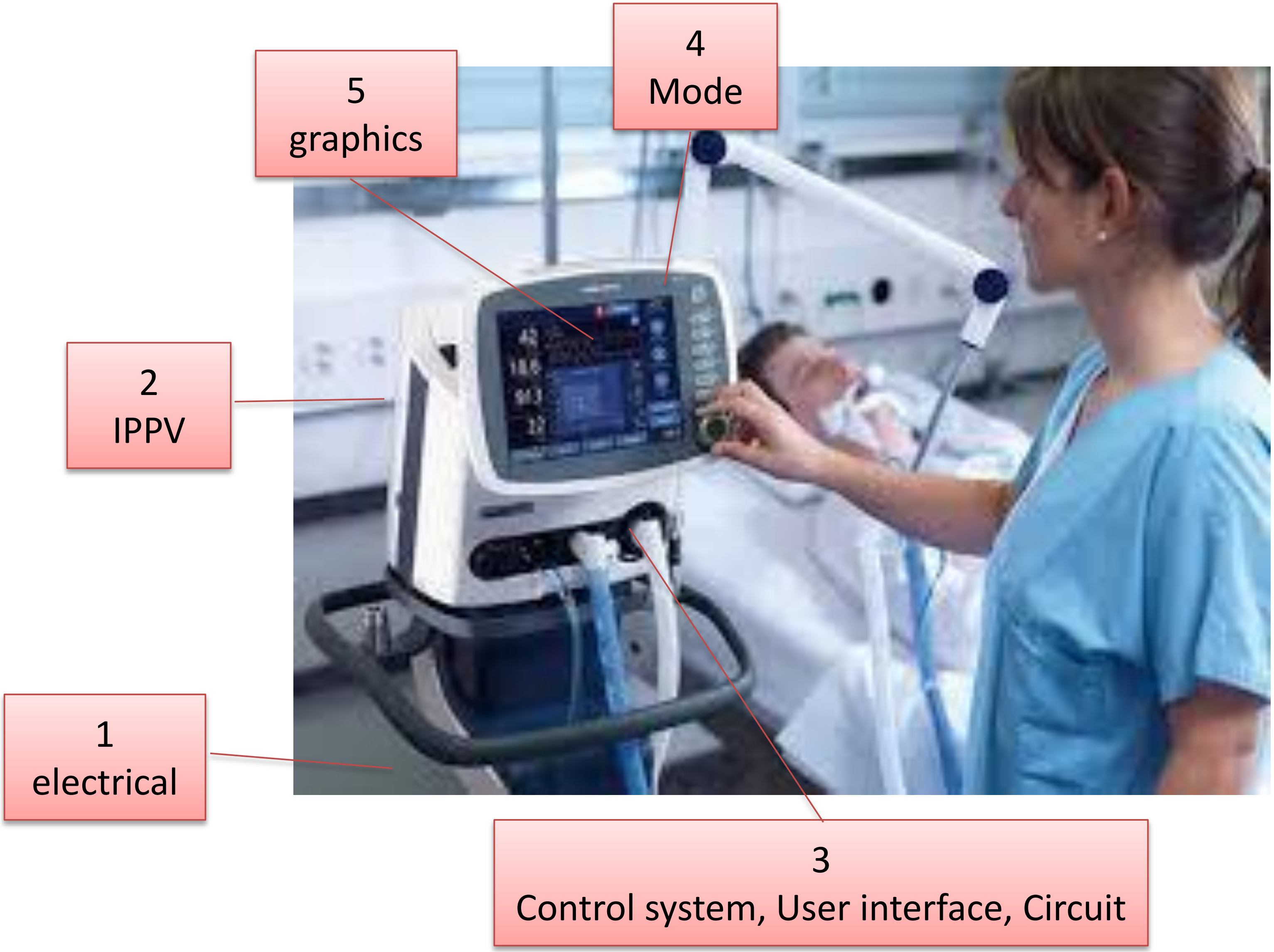
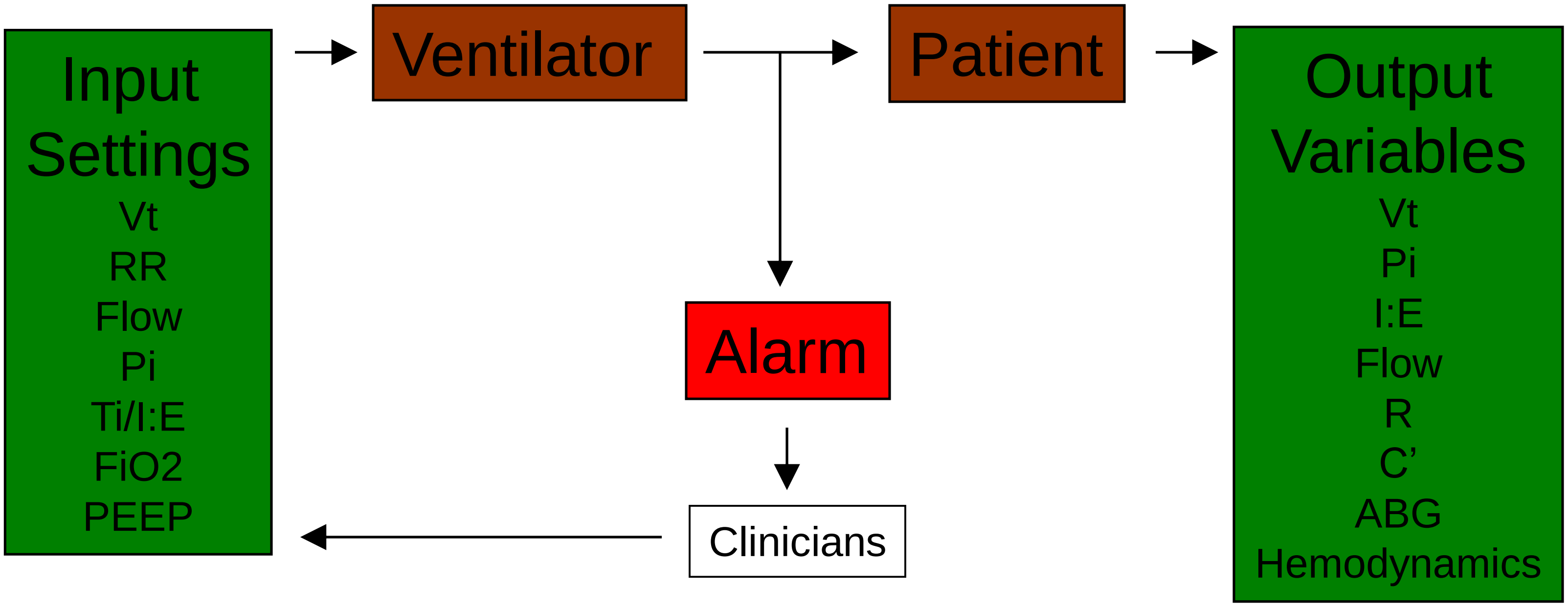


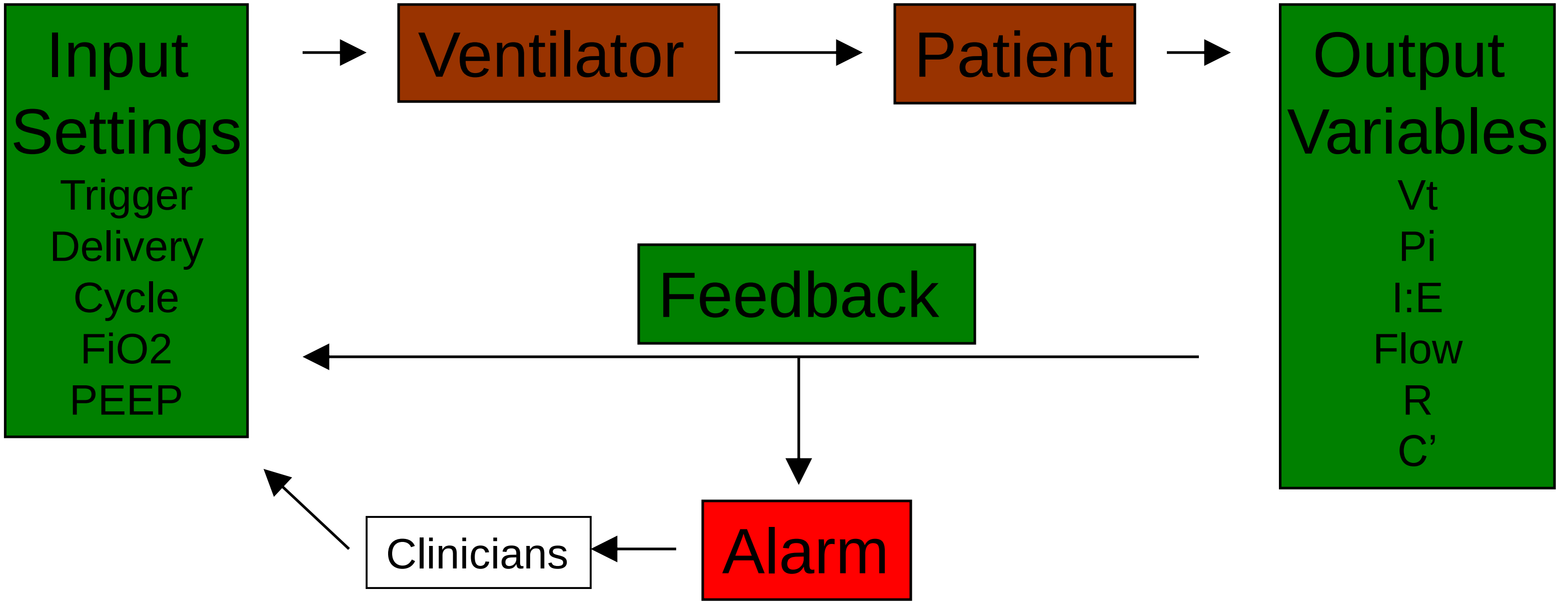
Figure 5-1 A simplified generic block diagram of the ventilator system.

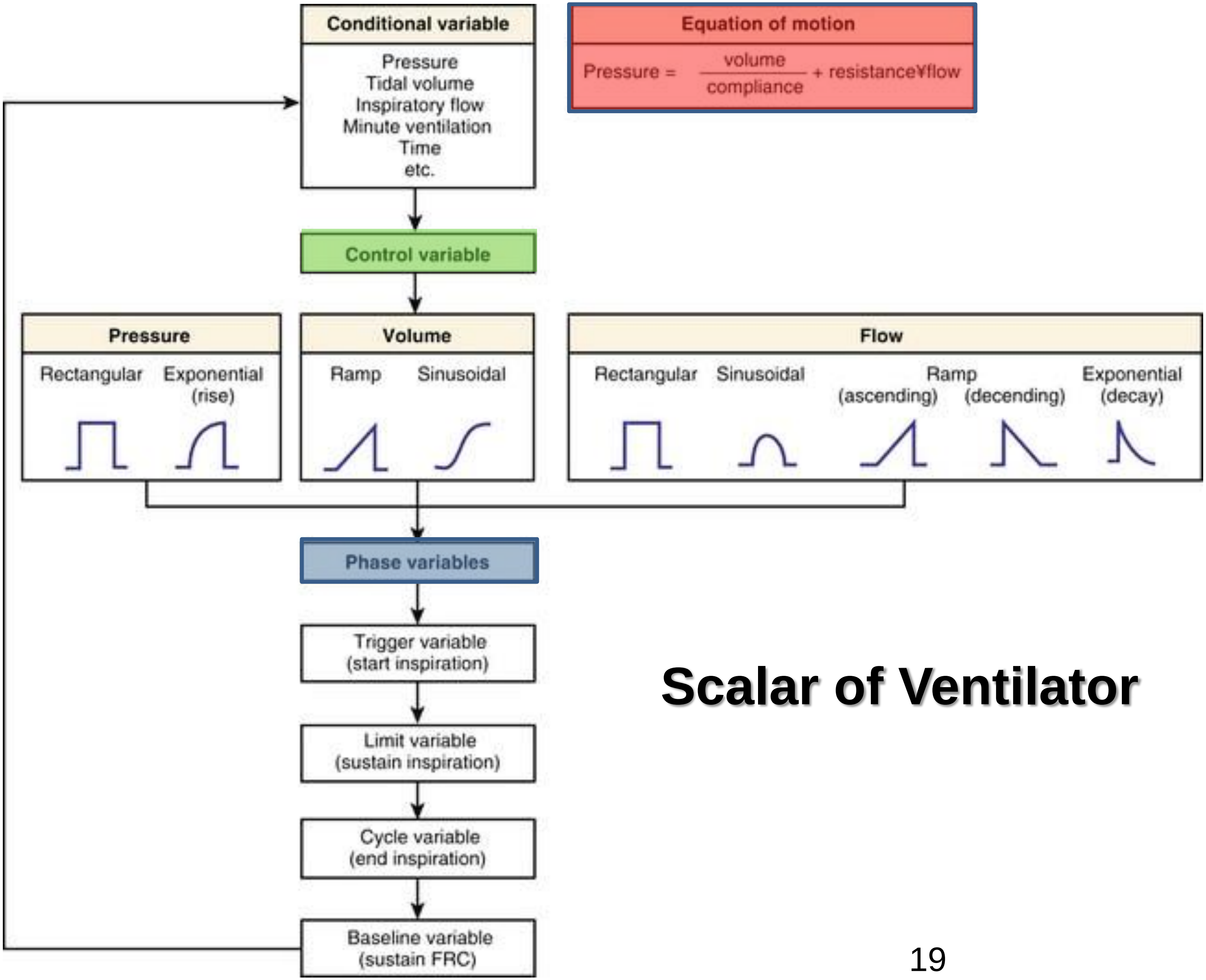

5
graphics
4
Mode
2
IPPV
1
electrical
3
Control system, User interface, Circuit

Open-Loop Control



Closed-Loop Control
servo control

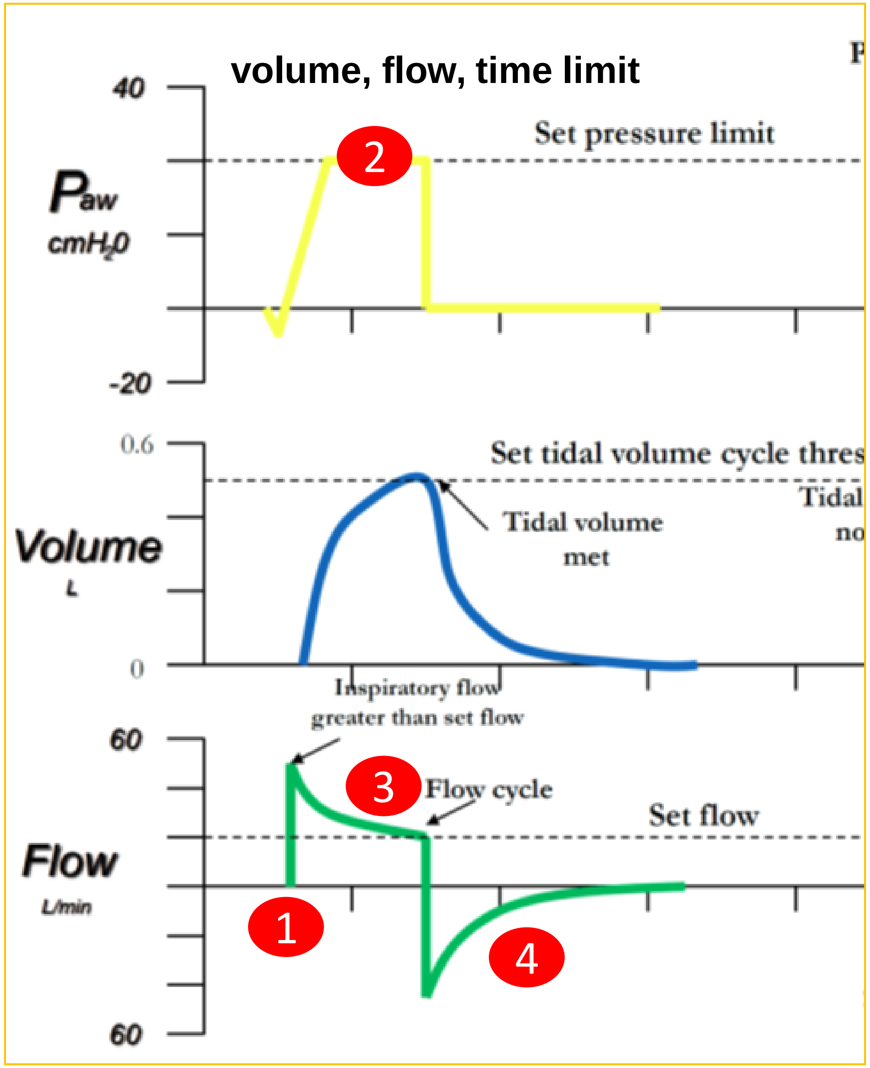




Scalar of Ventilator

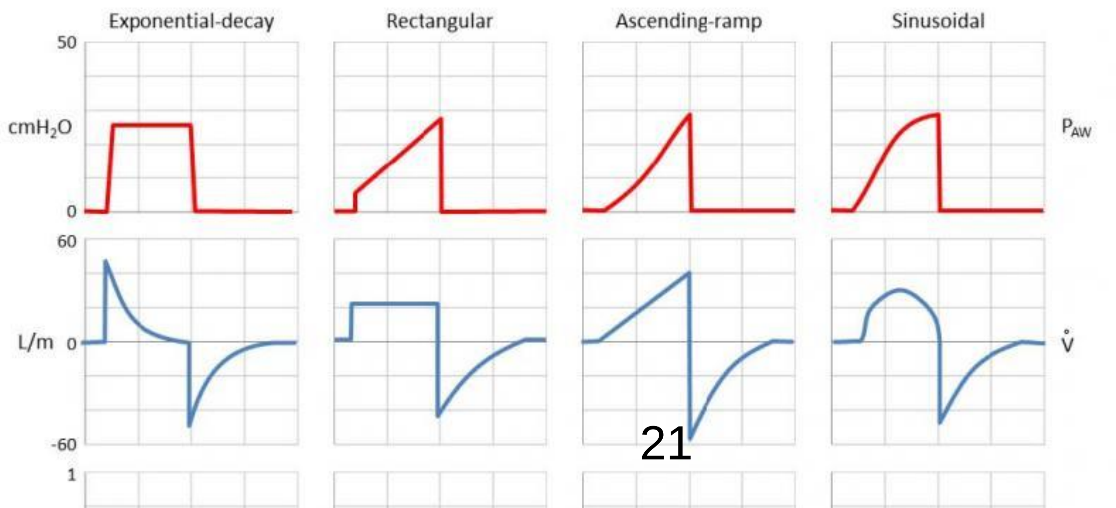
Four Phases of a Breath

1. End of expiration and beginning of inspiration (triggering) 開始吸氣
2. Delivery of inspiration (limiting)
3. End of inspiration and beginning of expiration (cycling) 吸氣轉為吐氣
4. Expiratory phase : **PEEP**



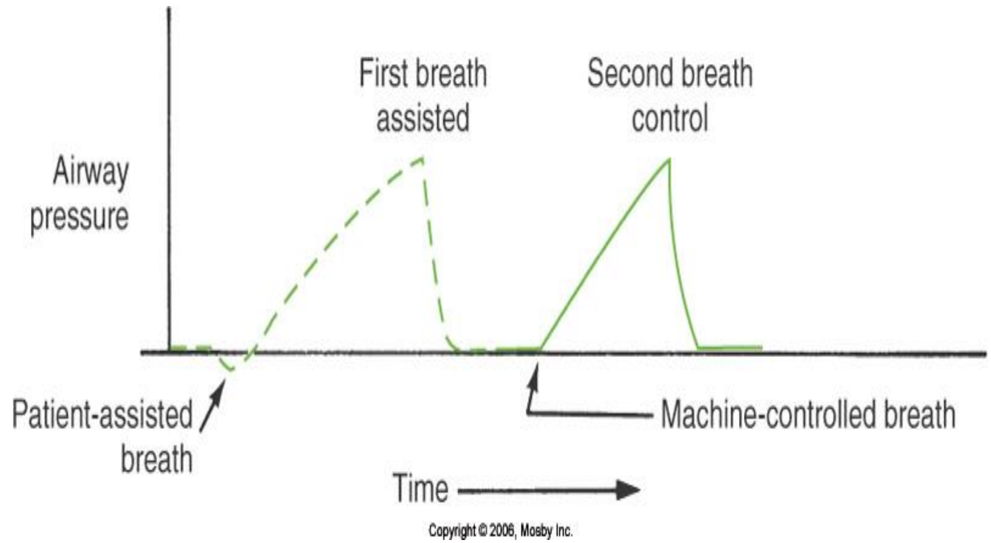
Initial Ventilator Setting: principle

- Mode selection
- FiO2 = 21-100% (<60%)
- Vt= 8-10 ml/kg, (ARDS 6 ml/IBW kg or ultra-low)
- R.R.= 12-15 /min, I/E : 1/2
- Flow= Vt/10 (40 - 80 L/min) Ti x F=Vt
- PEEP= 0-5 cmH_2O
- Flow pattern (e.g. constant flow, ascending or descending ramp)

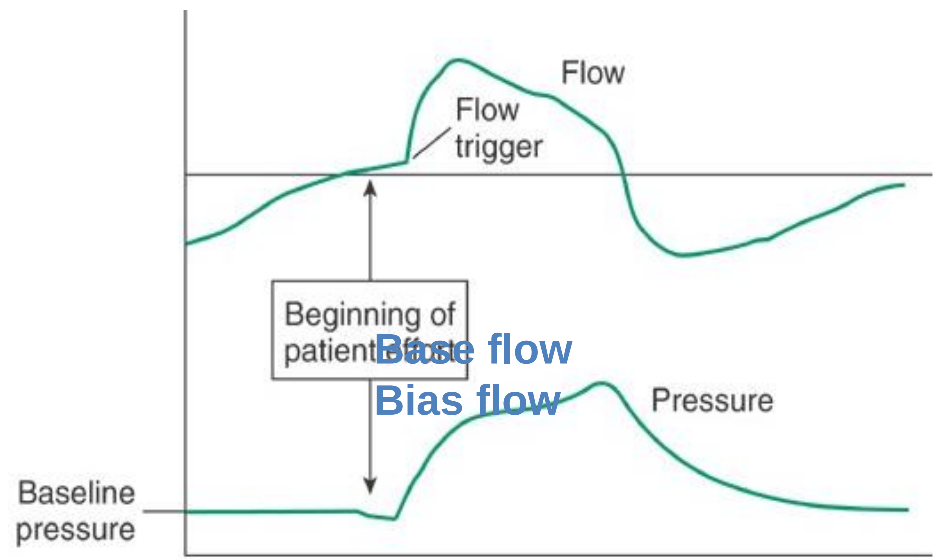


How a Breath is triggered

- **Pressure Triggered**
  - The patient's inspiratory effort causes a drop in pressure within the breathing circuit



- **Flow Triggered**
  - The ventilator detects a drop in flow through the patient circuit during exhalation



Ventilator Setting: limit for alarm

- Limit
  - high pressure alarm (PIP + 10 cmH_2O)
  - low pressure limit (10 cm H_2O)
- Low minute ventilation (RR x Vt, >3L/min)
- PEEP
- Tidal volume (6-10 ml/IBWkg acceptable)

Standard Modes of Ventilation

Full Support

PCV

ACV

Partial Support

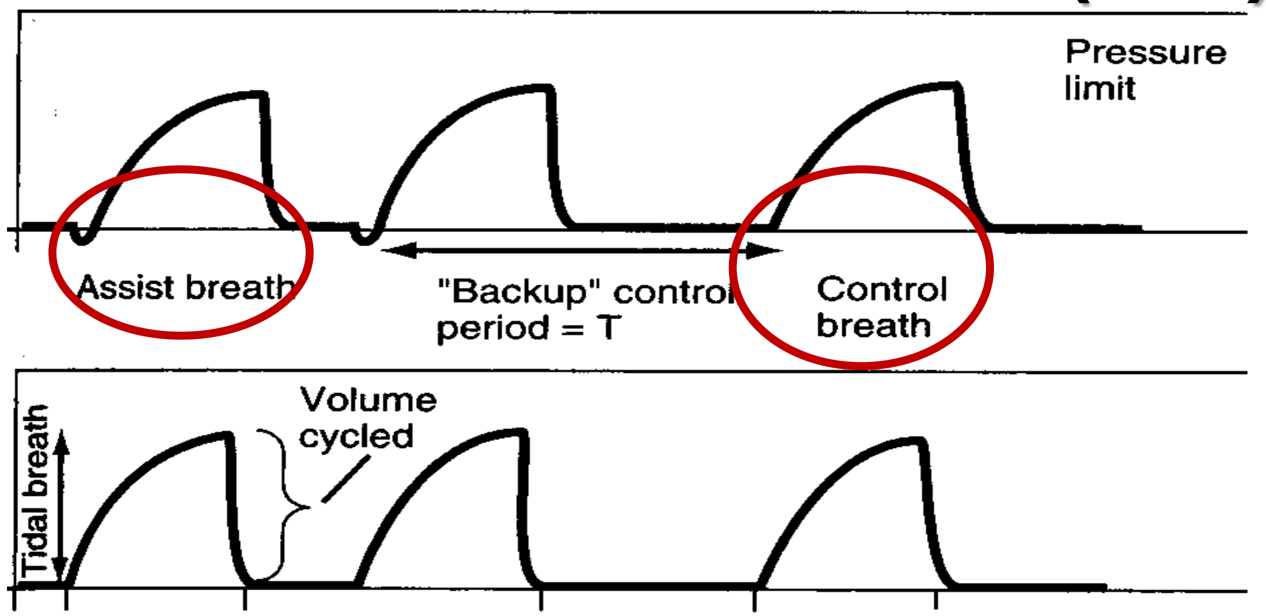
SIMV

PS

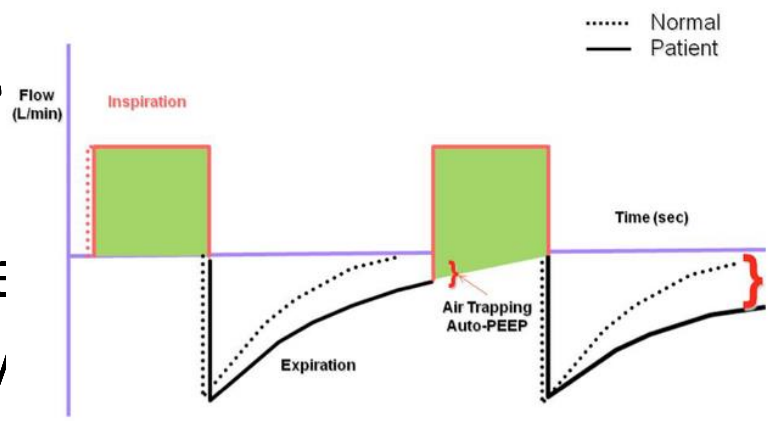
Spontaneous Breathing

CPAP

Ventilator Mode: Assist-Control ventilation (ACV)

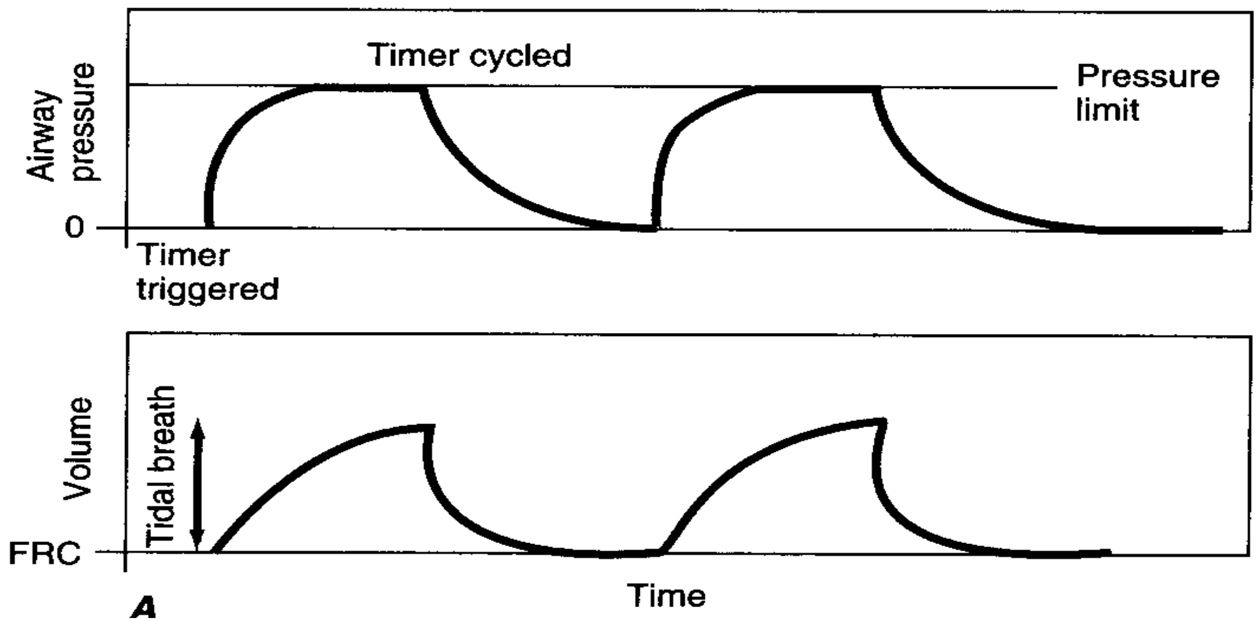


- Patient inspiratory effort or ve
  limit and volume-cycled) .
- Indications :for Paralyzed patie
  support, in patients need stable V



- Complications : (1) tachypnea with respiratory alkalosis . (2)auto-PEEP. (3)high pressure (must set high pressure limit)

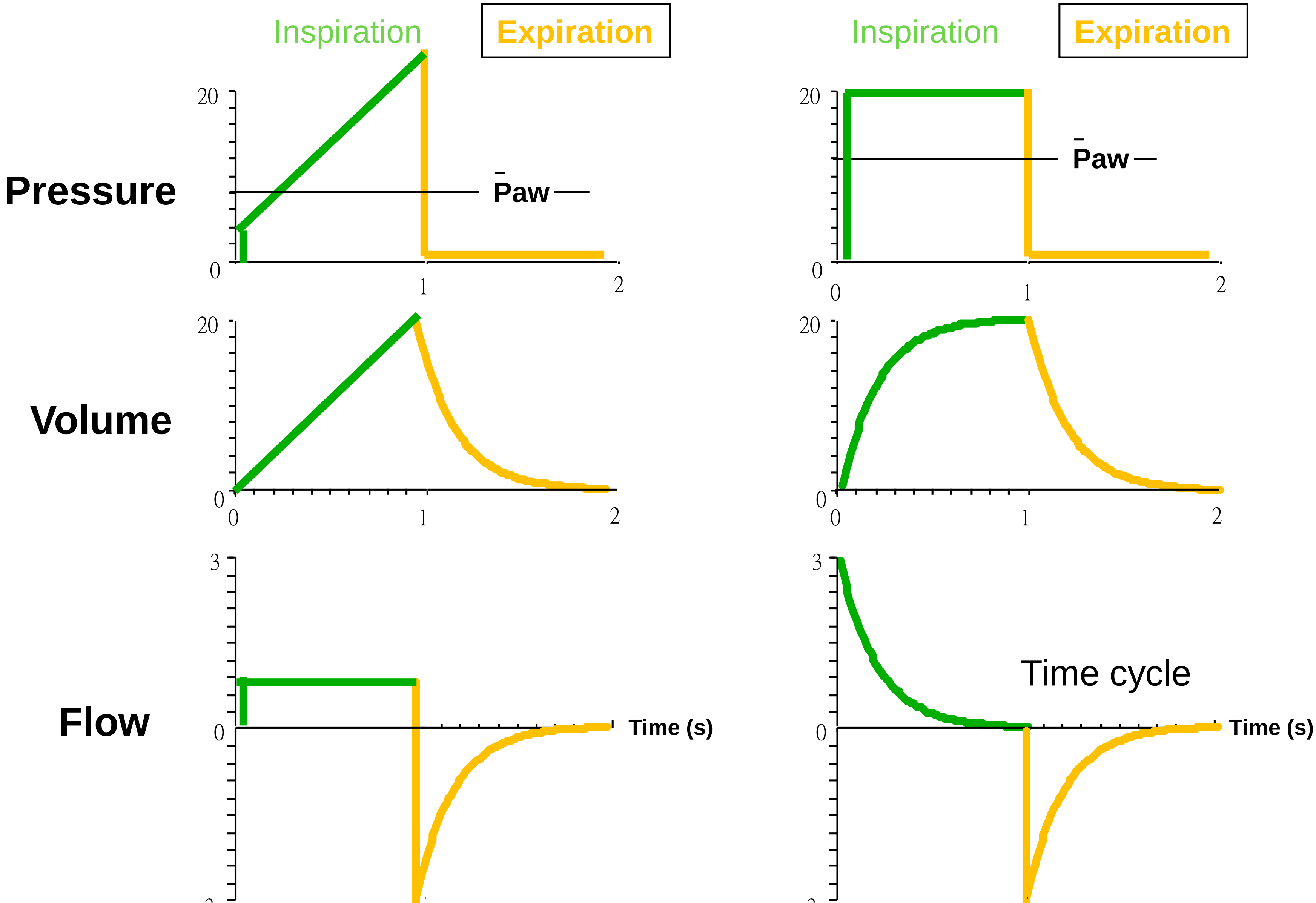
Ventilator Mode:
Pressure-Target Ventilation (PACV, PCV)



- Timer triggered, timer cycled (Ti) and pressure limited .
- Indications: high PIP or barotrauma (e.g. PNX), post-op thoracic surgical patient ,hypoxemia.
- Complications: variable tidal volume and minute ventilation, permissive hypercapnia.

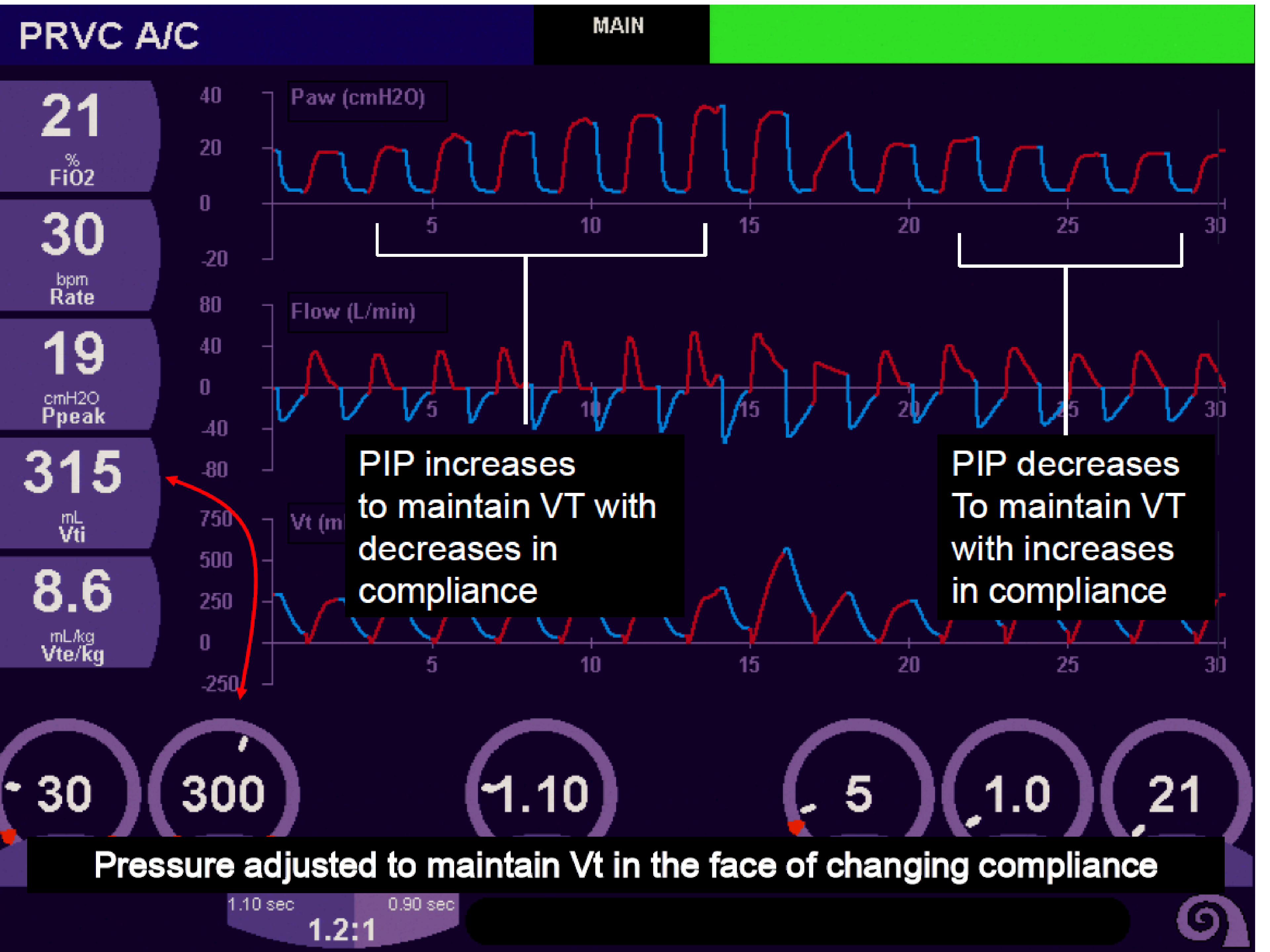
Volume/Flow Control

Pressure Control



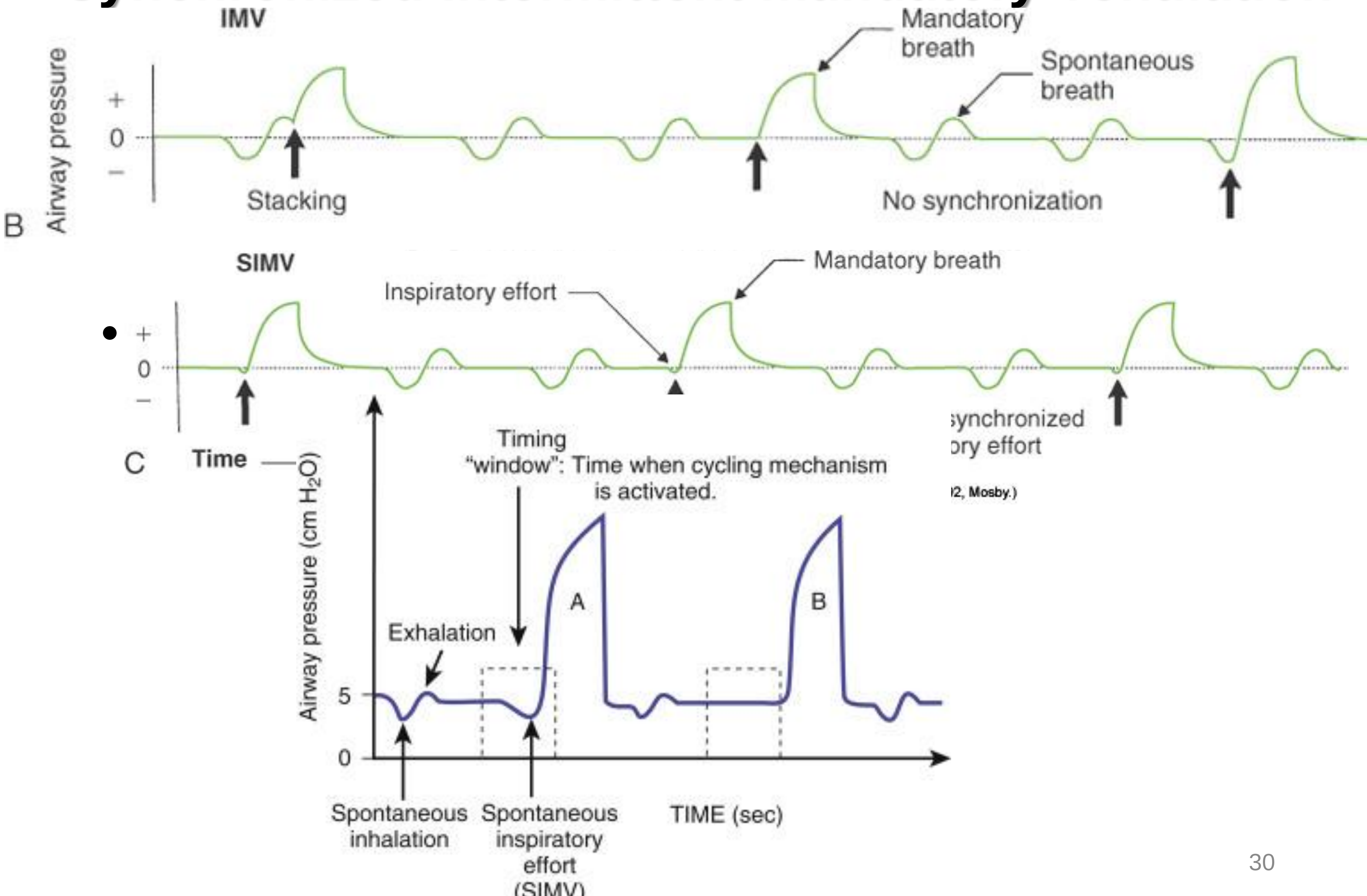
Ventilator mode: PRVC
pressure regulated volume control

- Time or patient triggered, time cycled, use the set



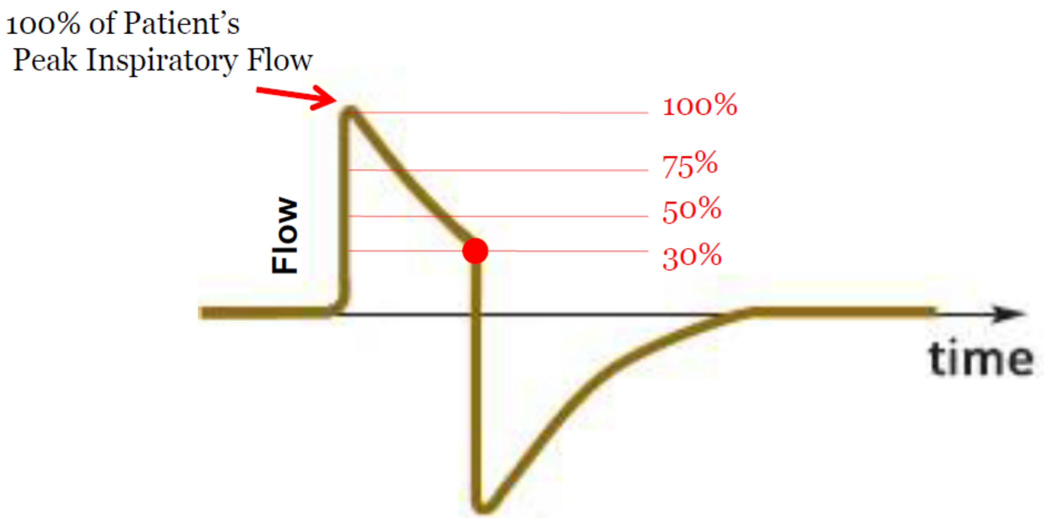
PRVC A/C
MAIN
21
%
FiO2
30
bpm
Rate
19
cmH2O
Ppeak
315
mL
Vti
8.6
mL/kg
Vte/kg
Paw (cmH2O)
Flow (L/min)
PIP increases to maintain VT with decreases in compliance
PIP decreases To maintain VT with increases in compliance
30
300
1.10
5
1.0
21
Pressure adjusted to maintain Vt in the face of changing compliance
1.10 sec
0.90 sec
1.2:1

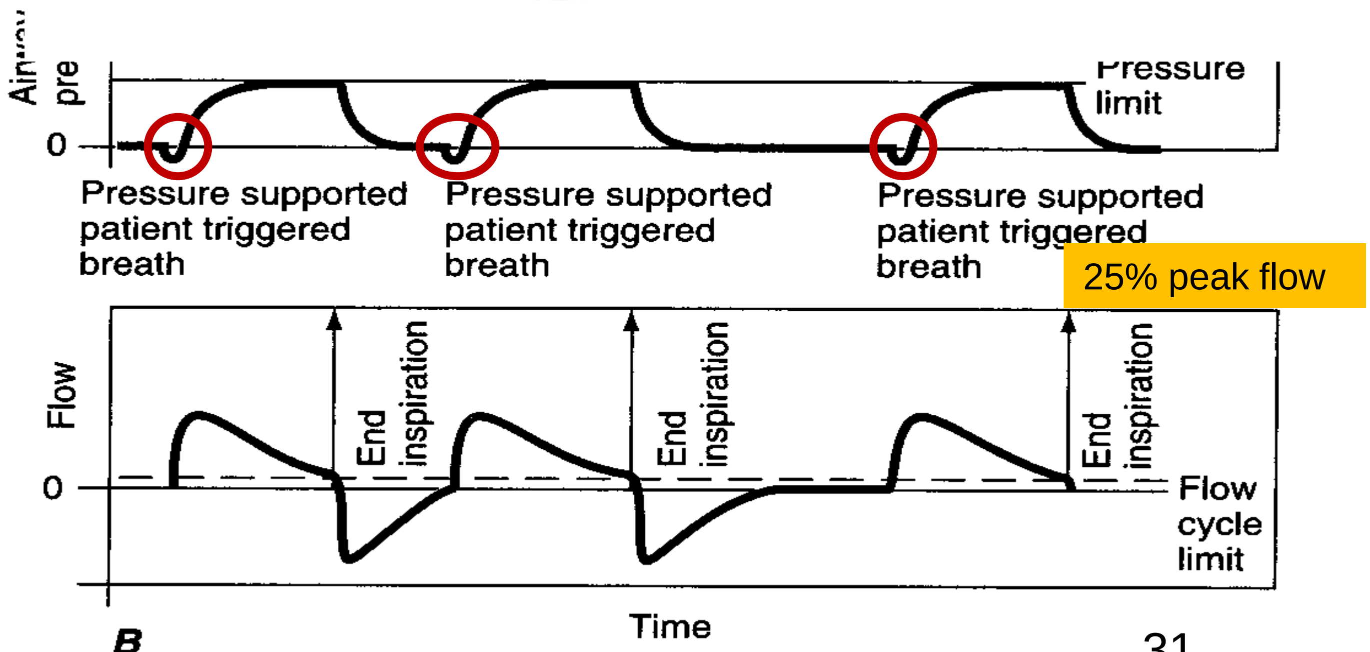
Ventilator Mode : SIMV
Synchronized Intermittent mandatory ventilation

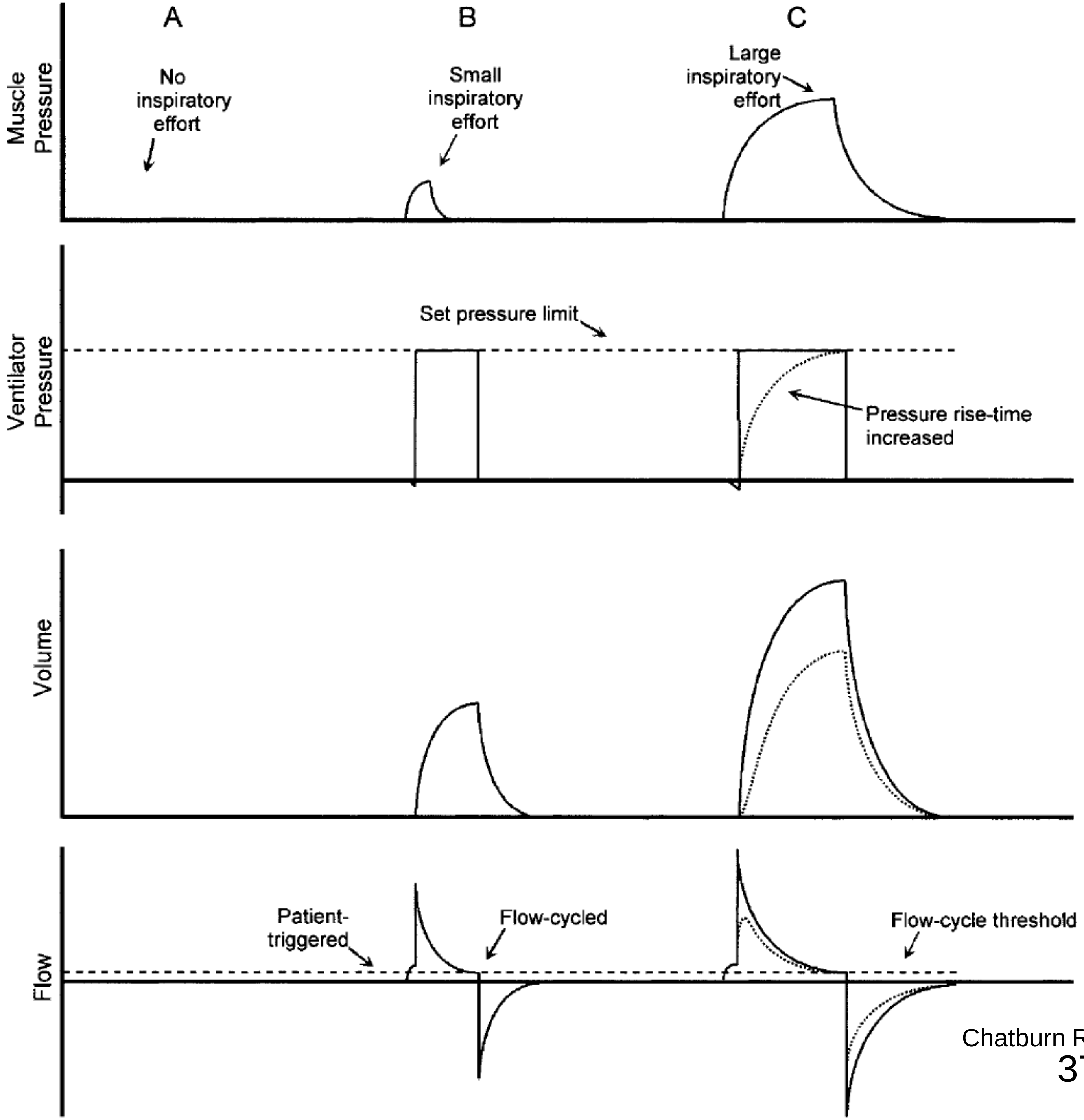


Inspiratory Cycle Off

- pati 25%
  flow
- Indi .







expiratory trigger sensitivity, ETS

Chatburn RL Respir care 2007;52:301-23

PS mode cycling-off criteria (expiratory trigger sensitivity, ETS)

flow	Ventilators
5L/min	PB7200
4L/min or 10%PF	Infrasonics star
10L/min or 25% PF	PB740
Adjust 1%-45% PF	PB760
Adjust 1%-80% PF	PB840, servo-i, servo-s
Adjust 5%-30% PF	Vela
Adjust 5%-45% PF	Avea
Adjust 5%-50% PF	e500
Adjust 10%-40% PF	Galileo, LTV1000, Elisee
Adjust 10%-45% PF	Espirit
Adjust 10%-80% PF	Inspiration
5%-30% PF	T-bird
5%-70% PF	Evita XL
5% PF	Servo 300
25% PF	**Evita-2, Evita-4, Savina, Servo900c, Veolar, Bird8400 ,Bear100,**
automatic	Bipap vision

TABLE 5 Advantages and Disadvantages of PS Mode

Pressure Supported Ventilation	
Advantages	**Disadvantages**
1. The patient can control the depth, length, and flow of each breath 2. Allows flexibility in ventilator support 3. Improves synchrony and diaphragmatic work	• Excessive level of support can result in: 1. Respiratory alkalosis 2. Hyperinflation 3. Ineffective triggering 4. Apneic spells • Suboptimal support can result in: 1. Diaphragmatic fatigue 2. Respiratory acidosis

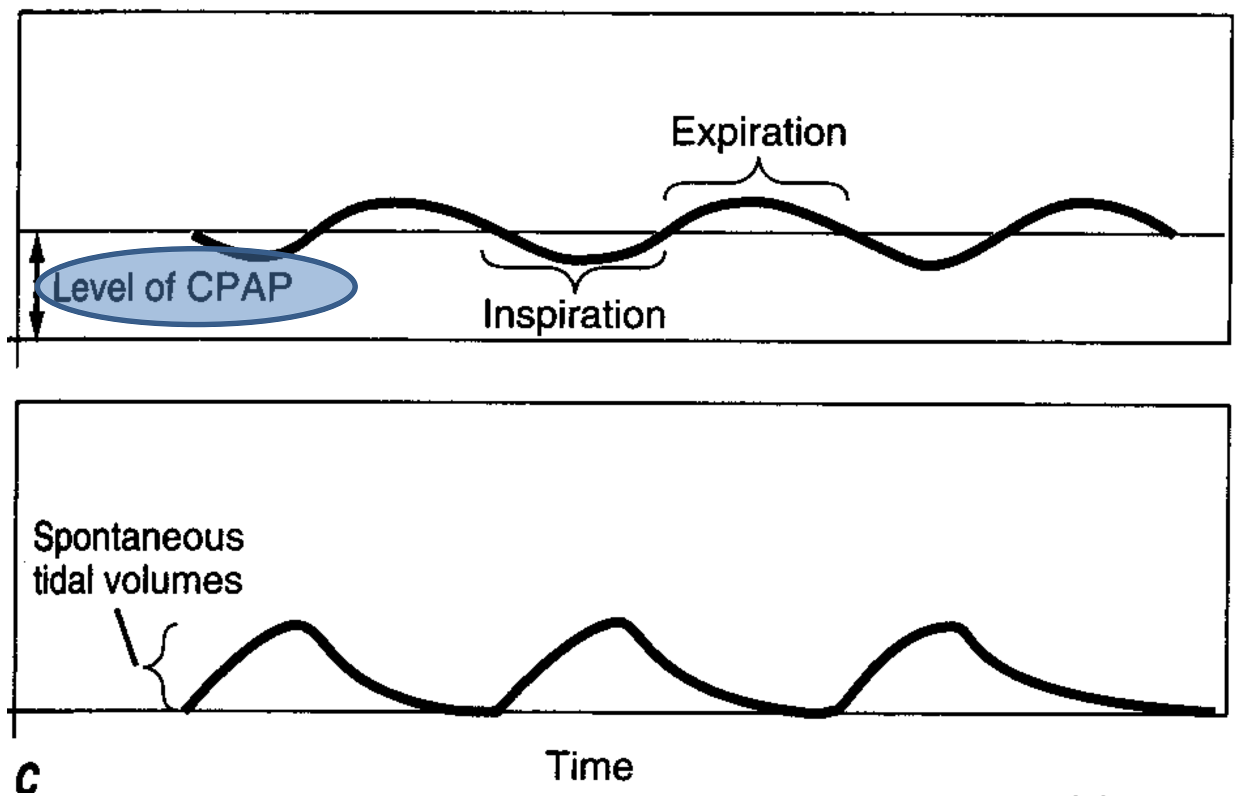
J Am Coll Cardiol 2018;72:1532–53]

Mode variables

Variables	Common options	Typical settings
Trigger	Time triggered	To provide RR of 12-20/min
	Flow triggered	2-3 L/min
	Pressure triggered	0.5-2 cmH_2O
Control	Flow controlled	Indirectly set by V_T(6-10 ml/kg), RR, I:E
	Pressured controlled	To provide V_T of 6-8 ml/kg
Cycling	Flow cycled	<25% peak flow
	Volume cycled	To provide V_T of 6-10 ml/kg
	Time cycled	Ti , to provide RR of 12-20

Ventilator Mode:
Continuous Positive airway pressure (CPAP)

- By spontaneous effort, specified pressure (0-20cmH2O)

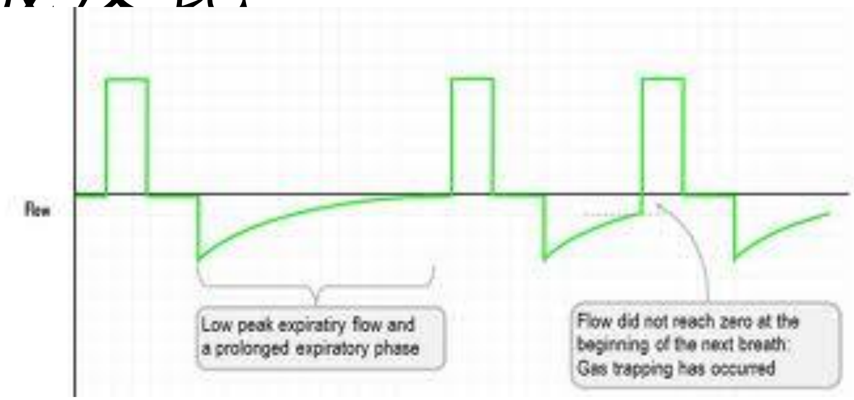


Single Modes

Mode	Trigger	Limited	Cycled	Variable	Setting
AC	Patient Time	Volume Pressure	Volume Time	R.R. **PIP**	Volume Flow RR.
PCV	Patient Time	Pressure	Time	Flow Volume	Pressure Ti R.R.
PS	patient	Pressure	Flow	Flow Volume R.R.	Pressure
CPAP	patient		Patient	Flow Volume R.R.	Pressure

Trouble shooting(I)

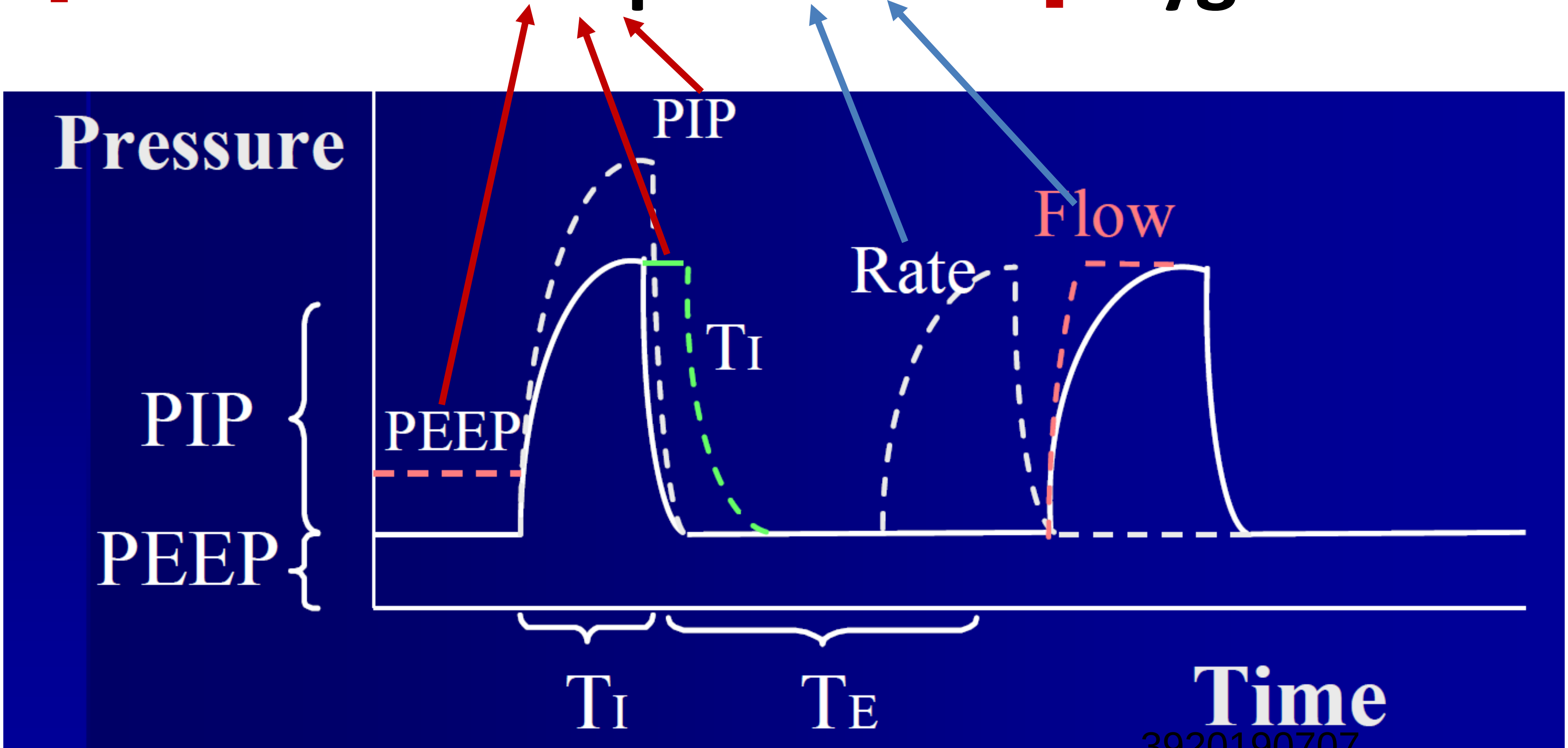
- $PaCO_2$ 太高:
  - –PaCO2 和 V_E(V_T X F)成反比
    - 增加 V_T (Pplat<30)
    - 增加 f (<30 avoid PE



- $PaCO_2$ 太低：
    - 減少 V_T
    - 減少 f
    - Add dead space

Factors increasing oxygenation

- $FiO_2 \propto$ oxygenation
- ⬆Mean alveolar pressure → ⬆oxygenation



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I. New Modes for Ventilator Weaning

Mechanical ventilator

Single mode
- PSV
- IMV
- PAC
- VAC

Dual mode
- VAPS
- PA
- Vol Supp
- PRVC
- APV
- Autoflow

Advanced closed loop
- ASV
- KBS (SmartCare®)
- PAV
- NAVA
- Fuzzy logic

* Others: ATC

Otis Equation in ASV

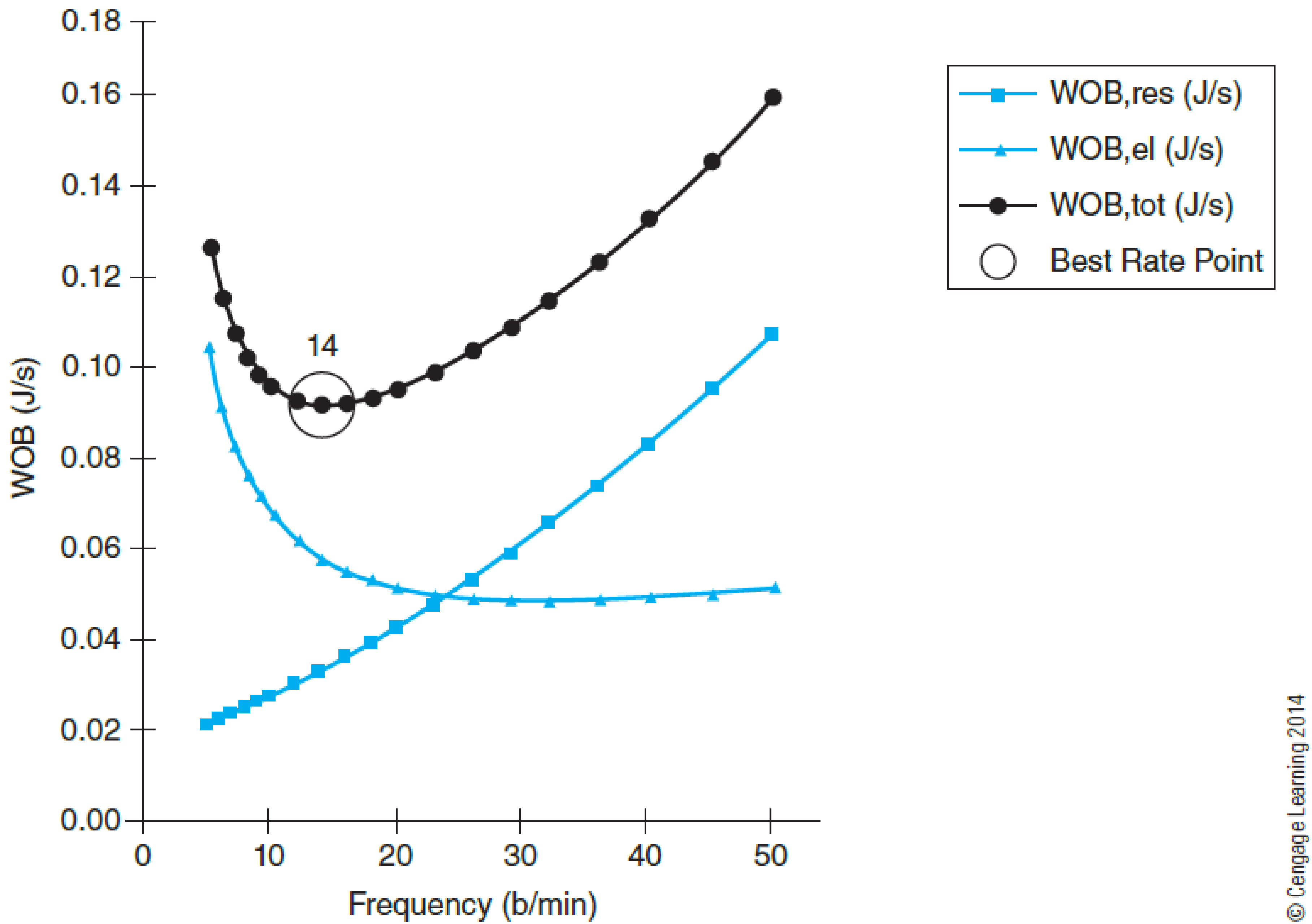
- The patient will breathe at a tidal volume and respiratory frequency that minimizes the elastic and resistive loads

Min WOB concept

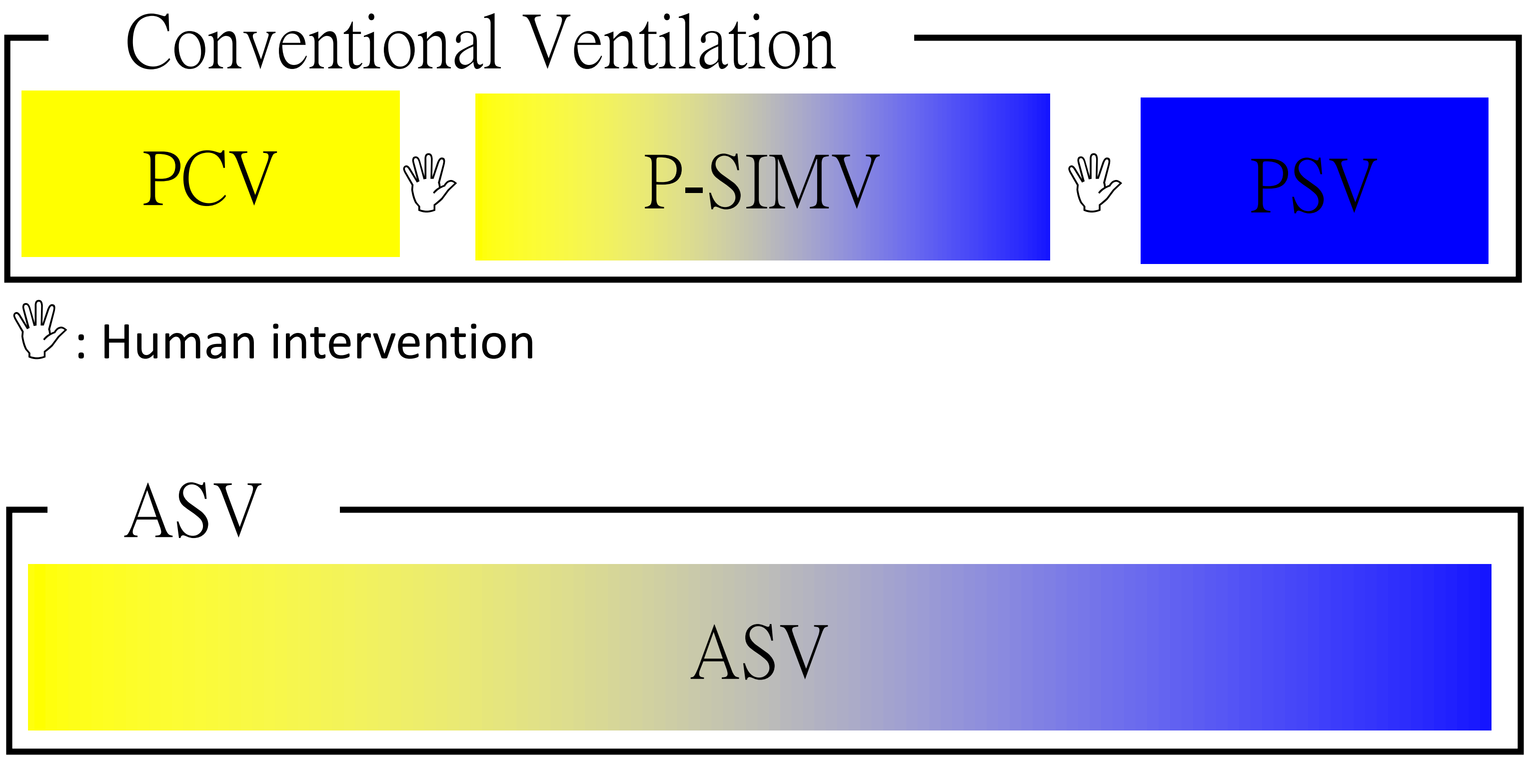
$$f = \frac{\sqrt{1 + 4\pi^2 RCe \bullet [(MV - f^* V_D)/V_D]} - 1}{2\pi^2 RCe}$$

Adapted from Otis et al, JAP 2:592,1950

RC: time constant = Compliance x Resistance
Vd ~ 2.2ml x BW (lean body mass in Kg)


0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
WOB (J/s)
0
10
20
30
40
50
Frequency (b/min)
14
WOB,res (J/s)
WOB,el (J/s)
WOB,tot (J/s)
Best Rate Point
© Cengage Learning 2014

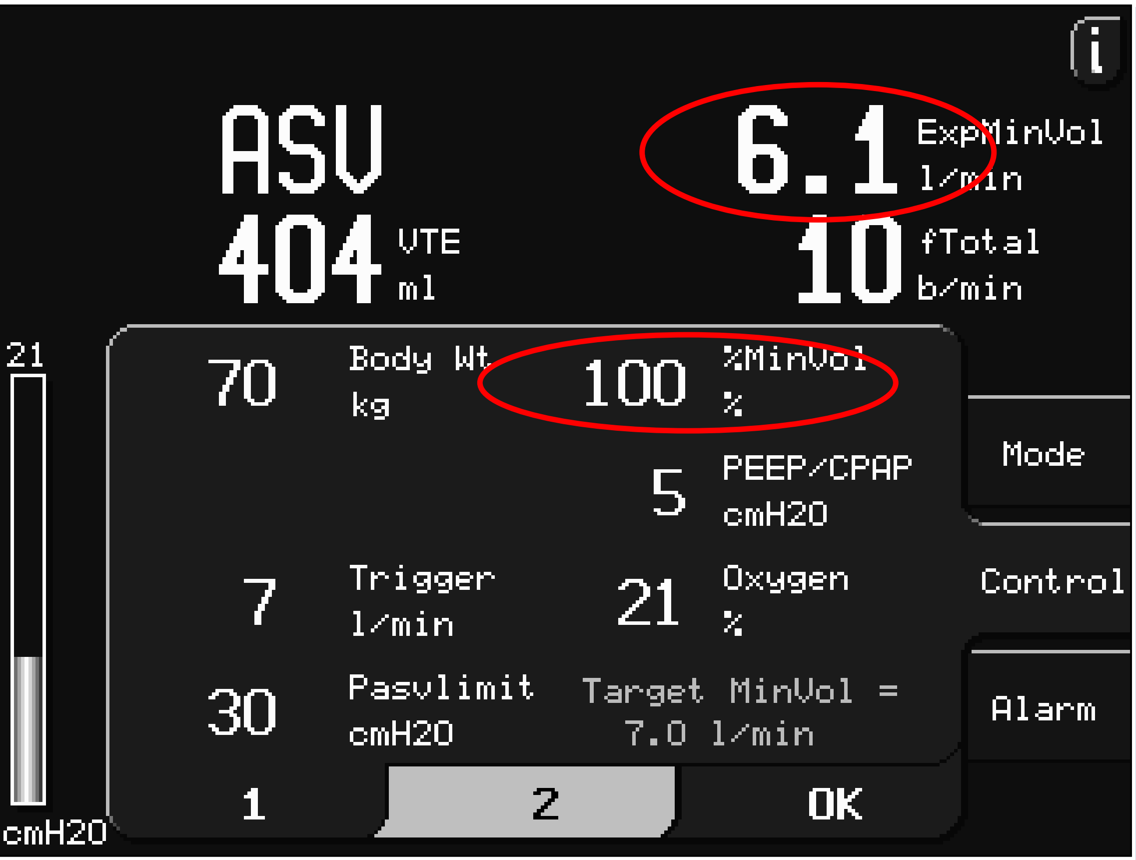
Dual Control Breath to Breath:
Adaptive Support ventilation (ASV)



: Human intervention

ASV changes from PCV to PSV without

Step 1_ 設定理想體重 (IBW)及每分鐘換氣量百分比 (VE%)



Ideal Body Weight IBW

Pediatric

Height (in.)	Height (cm)	IBW (kg)
19	50	6
21	55	6
23	60	7
25	65	8
27	70	8
29	75	9
31	80	10
33	85	11
35	90	12
37	95	14
39	100	15
41	105	17
43	110	19
45	115	20
47	120	23
49	125	25
51	130	28
53	135	31
55	140	34
57	145	37
59	150	41

Adapted from Traub SL. Comparison of methods of estimating creatine clearance in children. Am J Hosp Pharm 1980;37:195-201

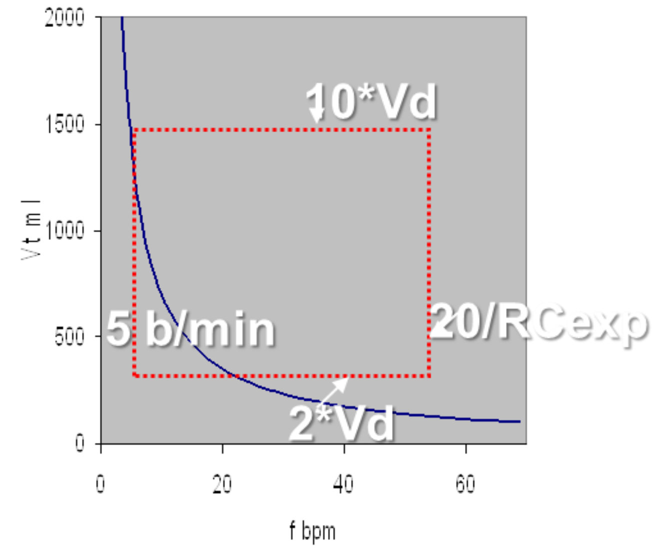
Adult

Height (ft)	Height (m)	IBW Male	IBW Female
5'0"	1.52	50	46
5'1"	1.55	52	48
5'2"	1.57	55	50
5'3"	1.60	57	52
5'4"	1.62	59	55
5'5"	1.65	62	57
5'6"	1.67	64	59
5'7"	1.70	66	62
5'8"	1.72	68	64
5'9"	1.75	71	66
5'10"	1.77	73	69
5'11"	1.80	75	71
6'0"	1.82	78	73
6'1"	1.85	80	75
6'2"	1.88	82	78
6'3"	1.90	85	80
6'4"	1.93	87	82
6'5"	1.95	89	85
6'6"	1.98	91	87
6'7"	2.00	94	89

Source : Pennsylvania Medical Center

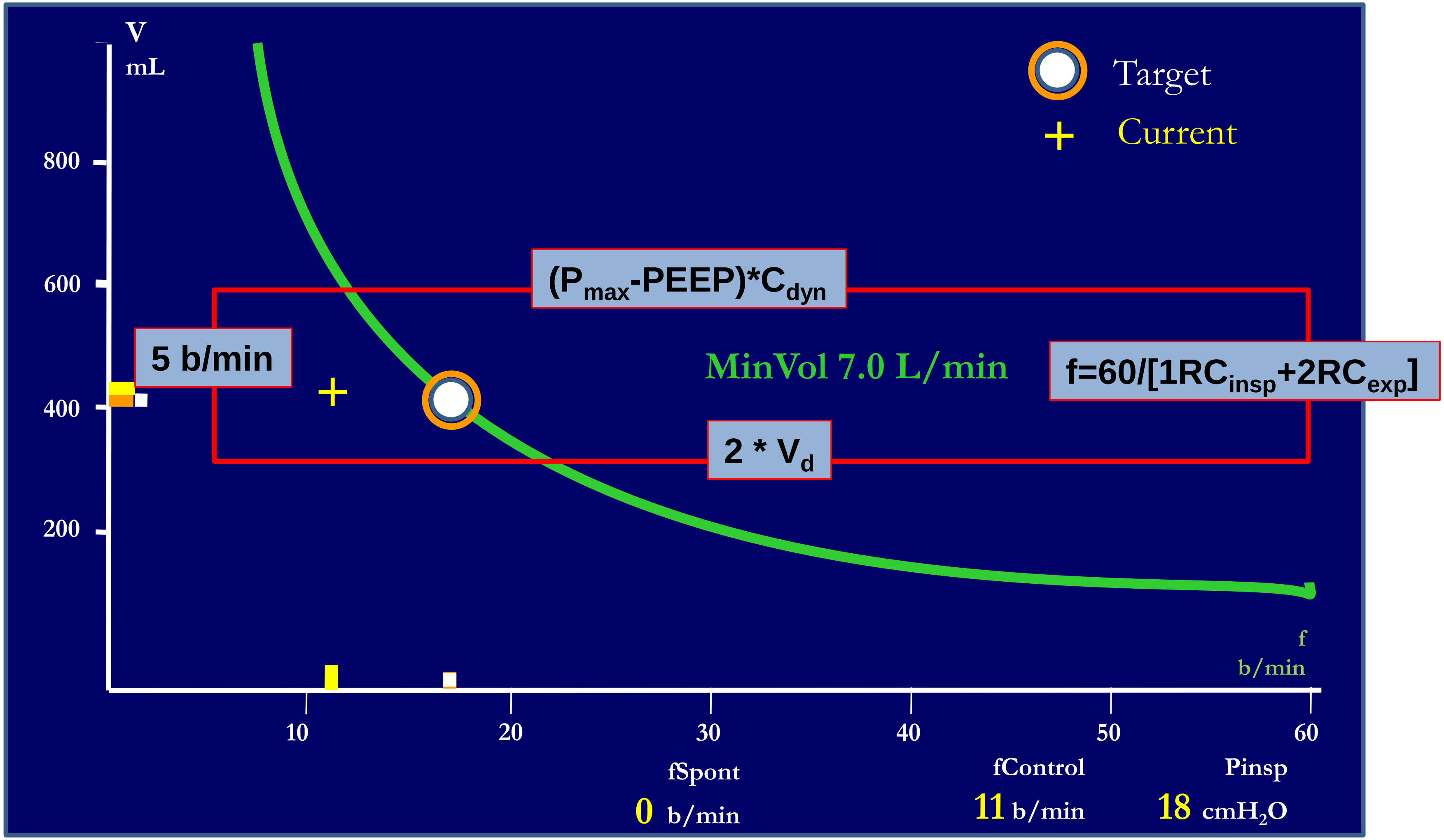
STEP 2_ ASV 3 test breath(得到病患資料 R, C, RCe)

STEP 3_ ASV 形成安全框框保護病人

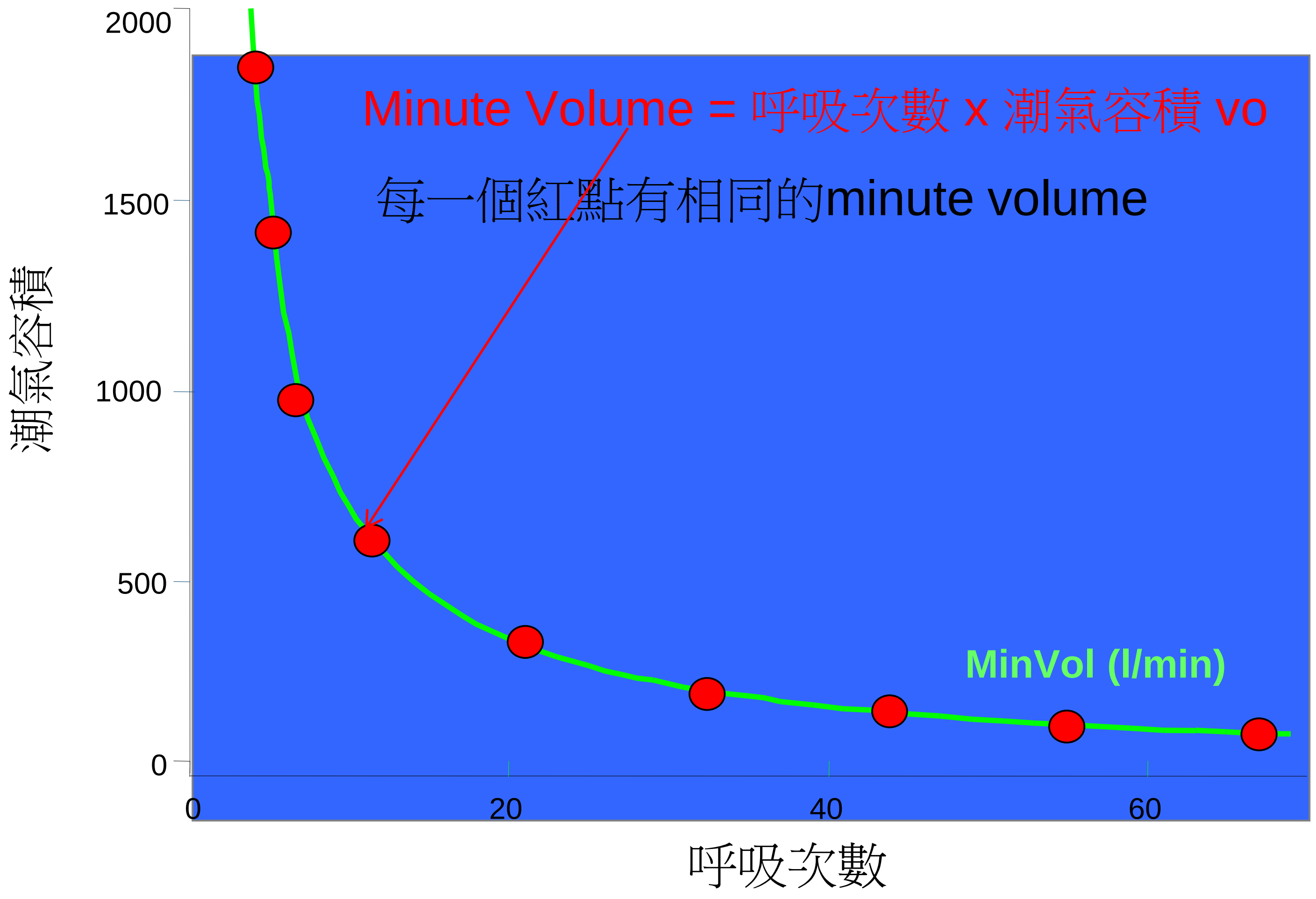


Parameters	Minimum Limit	Maximum Limit
Inspiratory pressure	PEEP + 5 cmH_2O	P_{high} + 10 cmH_2O
Tidal volume	4.4 ml/kg BW (2*V_{DS})	22 ml/kg BW (10*V_{DS})
Mandatory rate	5 /min	60 /min
Inspiratory time	RC_{Exp} or 0.5 sec	2*RC_{Exp} or 3 sec
Expiratory time	2*RC Exp	12 sec

The Safety Window: low rate/volume limits

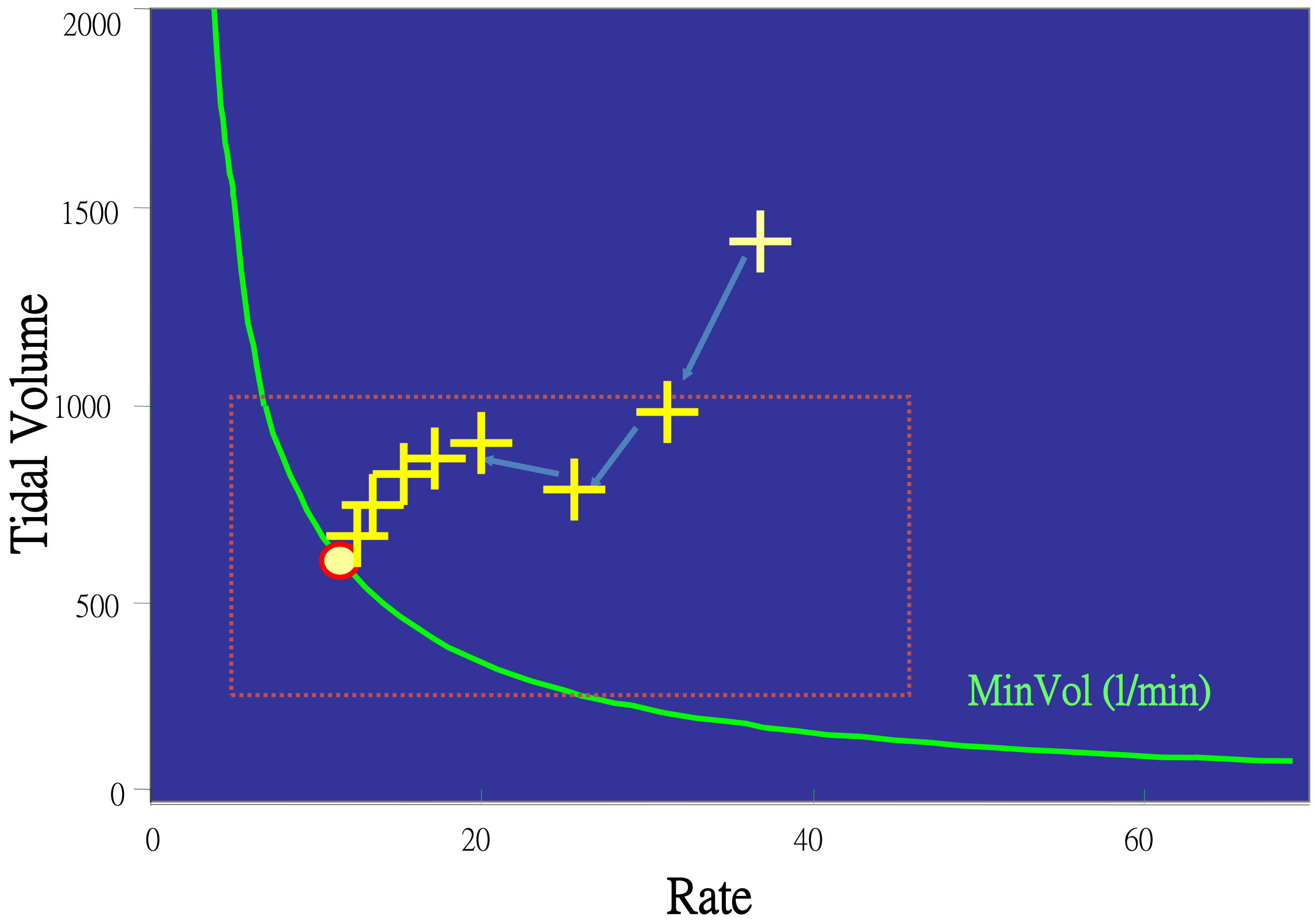


Step 4: 理想的呼吸次數,潮氣容積 (作功最小, 最舒服)

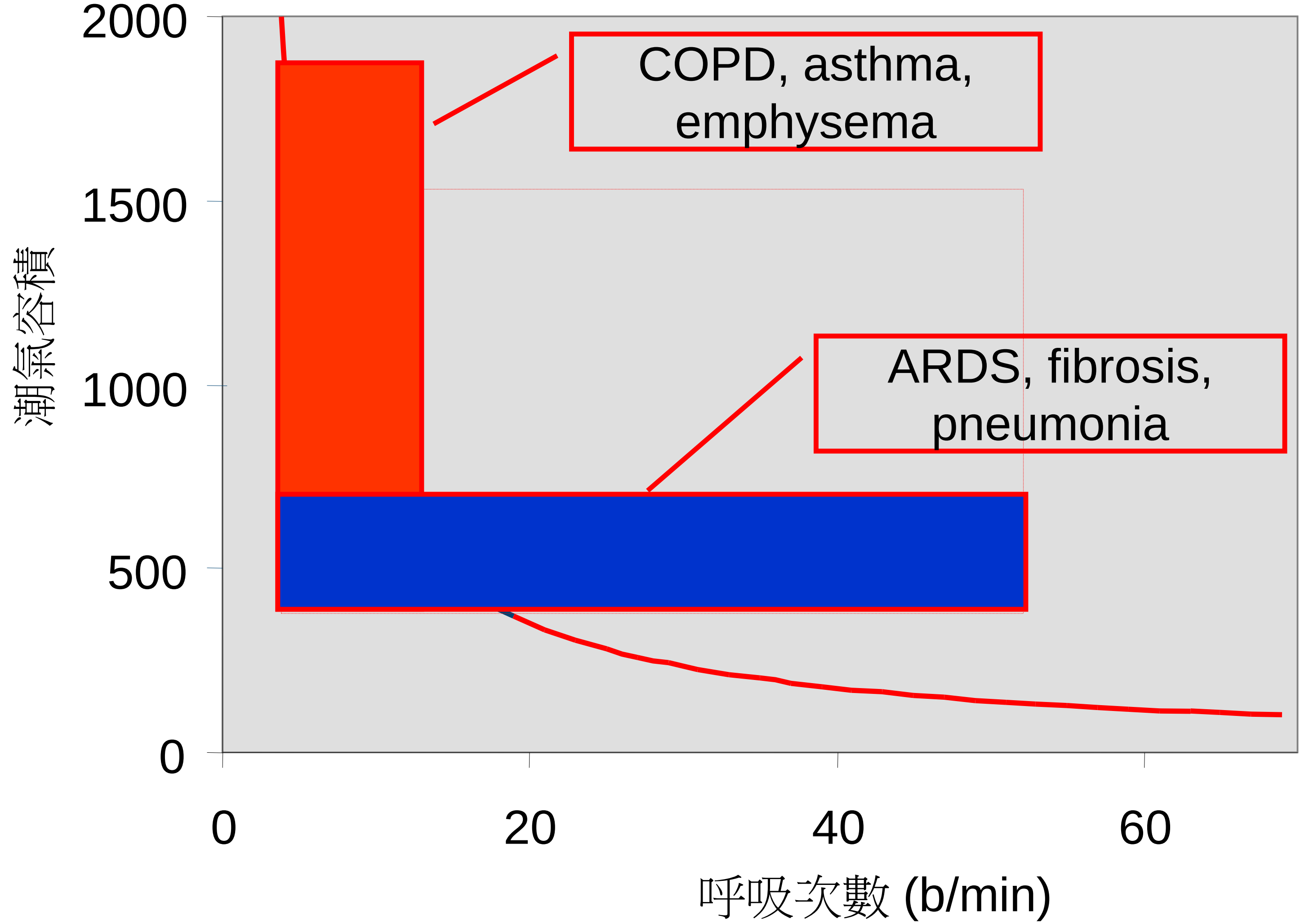


Step 5_ A S V自動調整:Pinsp & fSIMV趨近理想值

Step 6_ User 評估增減 % (MV)



Safe frame and underlying lung diseases



ASV
Adult
Patient
Additions
Modes
40
5
18 Ppeak cmH2O
11 Pmean cmH2O
10
4
4.1 ExpMinVol l/min
750
250
350 VTE ml
23
3
10 fTotal b/min
Patient
18 Ppeak cmH2O
18 Pplateau cmH2O
11 Pmean cmH2O
5 PEEP/CPAP cmH2O
5.0 Pminimum cmH2O
1 / 6
Paw cmH2O
40
20
0
-10
1 2 3 4 5 6 7 8 9 10
s
Flow L/min
100
50
0
-50
-100
Rinsp
9
cmH2O/l/s
Cstat
24
ml/cmH2O
170 cm, Male
800
600
400
200
0
V ml
Target
Current
MinVol
6.6
l/min
f b/min
0 10 20 30 40 50 60
fSpont
0
b/min
fControl
10
b/min
Pinsp
14
cmH2O
100 % %MinVol
5 cmH2O PEEP/CPAP
50 % Oxygen
Controls
Alarms
Monitoring
Graphics
Tools
Events
System
INT
AC

ASV (Adaptive Support Ventilation)

Disadvantages and Risks

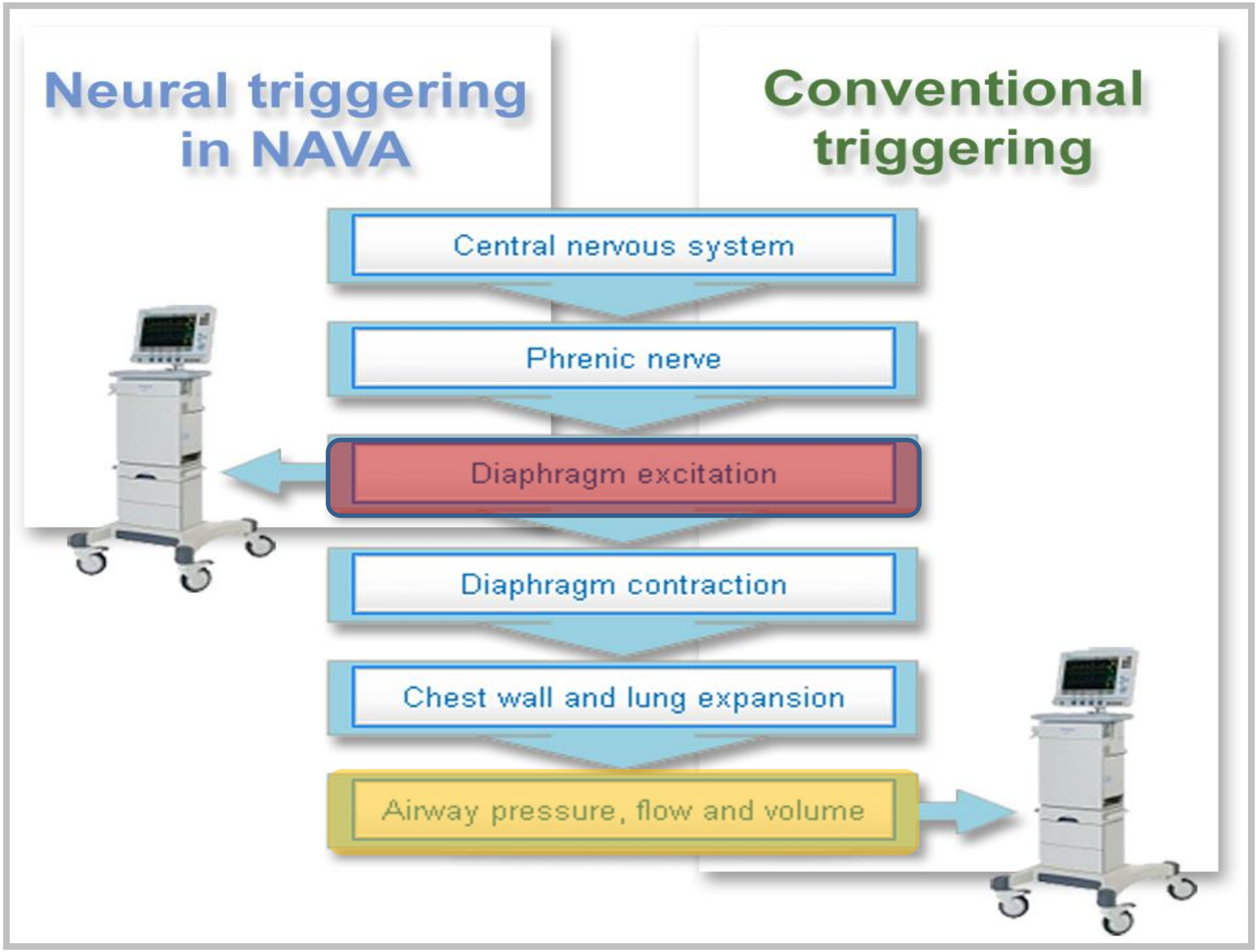
- Inability to recognize and adjust to changes in alveolar VD
- Possible respiratory muscle atrophy
- Varying mean airway pressure
- In patients with COPD, a longer TE may be required
- A sudden increase in respiratory rate and demand may result in a decrease in ventilator support

Advantages

- Guaranteed VT and VR
- Minimal patient WOB
- Ventilator adapts to the patient
- Weaning is done automatically and continuously
- Variable Volume to meet patient demand
- Decelerating flow waveform for improved gas distribution
- Breath by breath analysis

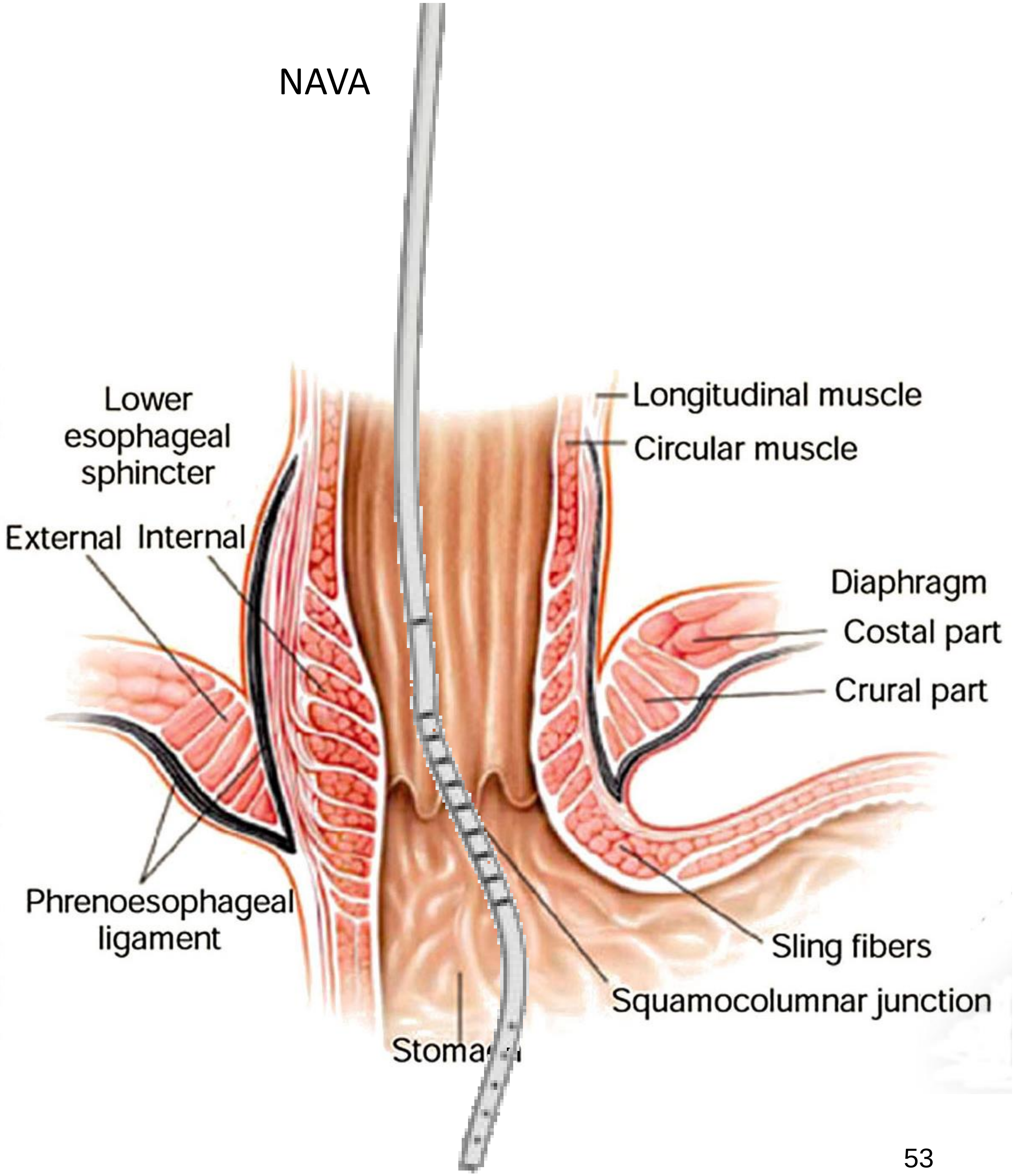
Neurally Adjusted Ventilatory Assist

NAVA CONCEPT

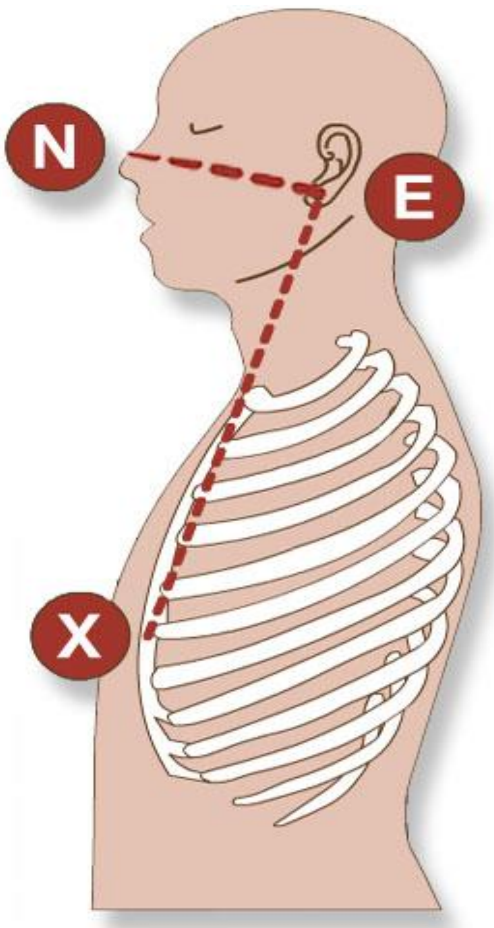


Picture adapted from
Nature 1999

NAVA

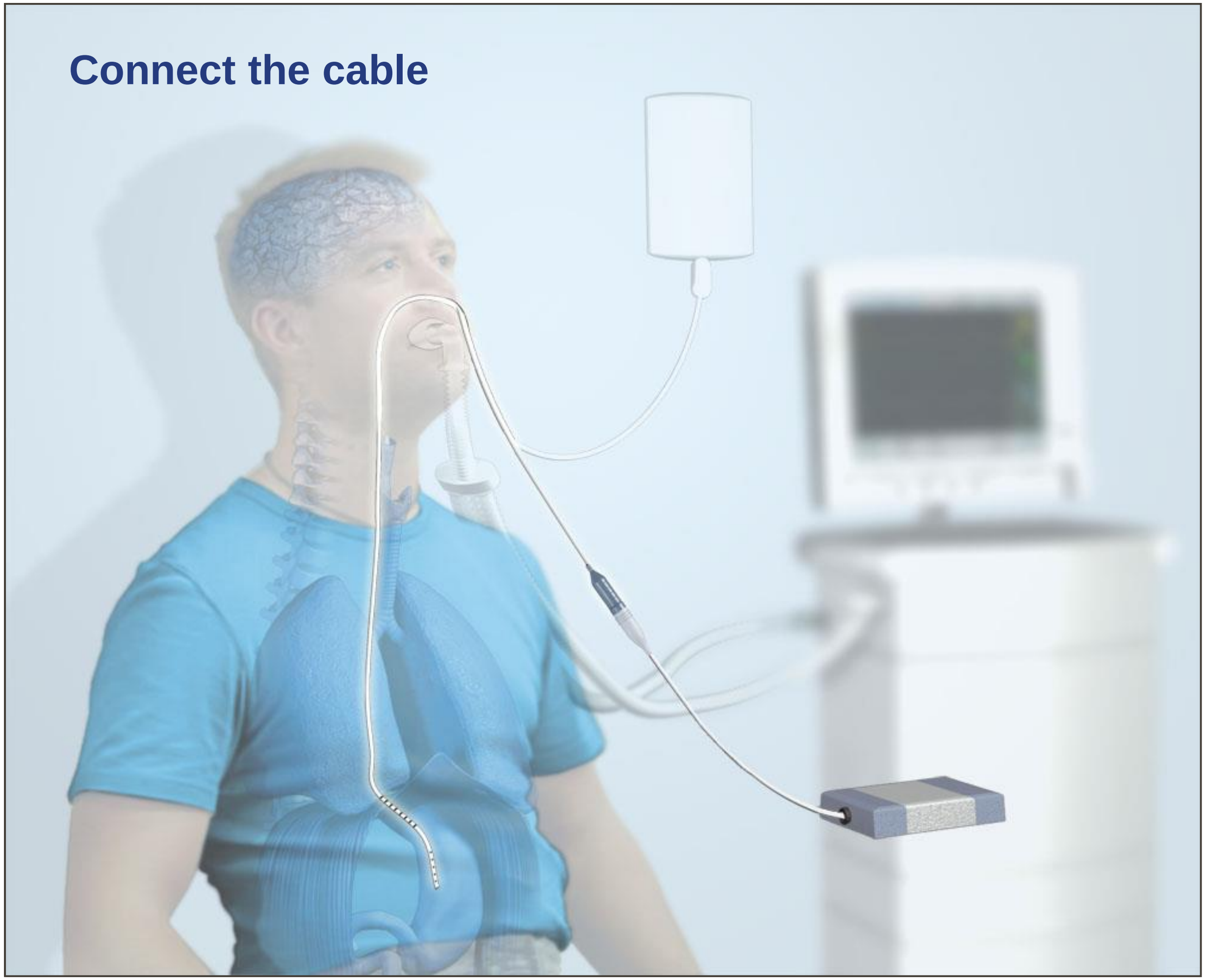

Lower
esophageal
sphincter
External
Internal
Phrenoesophageal
ligament
Longitudinal muscle
Circular muscle
Diaphragm
Costal part
Crural part
Sling fibers
Squamocolumnar junction

測量NEX長度，計算Edi Catheter置入病人長度



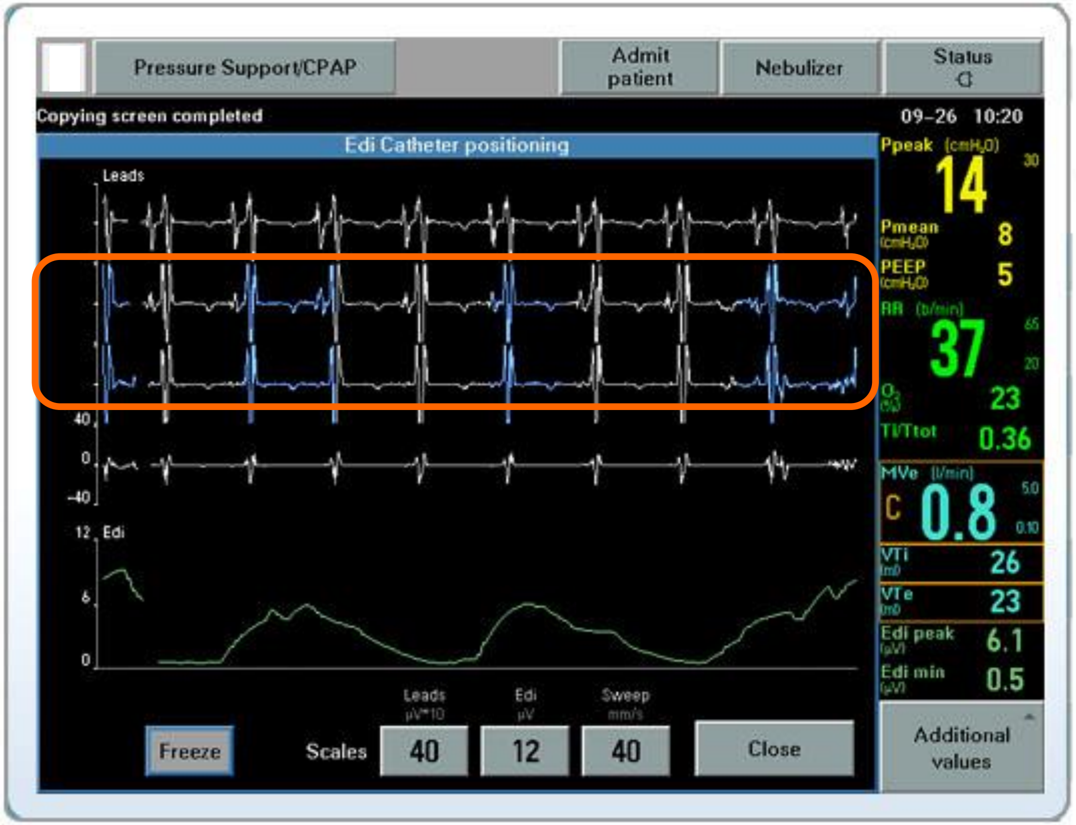
Insertion distance Y for nasal insertion	
Fr/cm	**Calculation of Y**
16 Fr	NEX cm x 0.9 + 18 = Y cm
12 Fr	NEX cm x 0.9 + 15 = Y cm
8 Fr 125 cm	NEX cm x 0.9 + 18 = Y cm
8 Fr 100 cm	NEX cm x 0.9 + 8 = Y cm
6 Fr 50 cm	NEX cm x 0.9 + 3.5 = Y cm
6 Fr 49 cm	NEX cm x 0.9 + 2.5 = Y cm

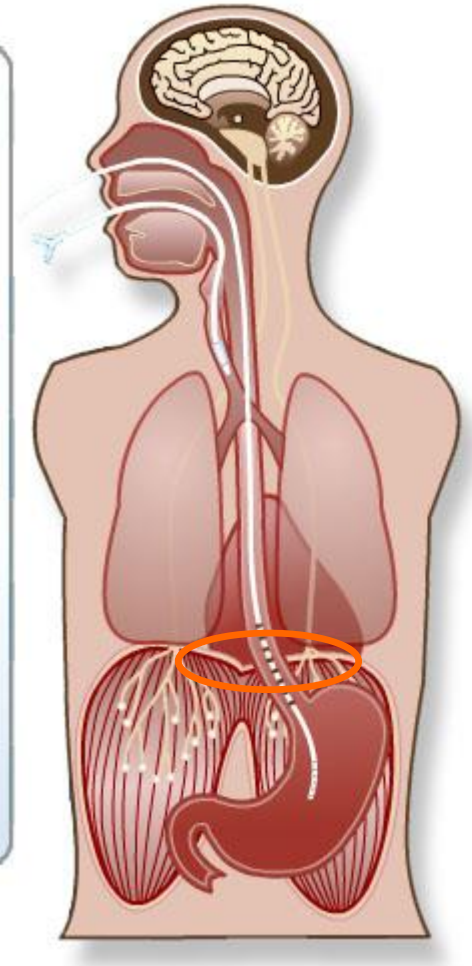
EDI CATHETER POSITIONING PROCEDURE



EDI CATHETER POSITIONING PROCEDURE

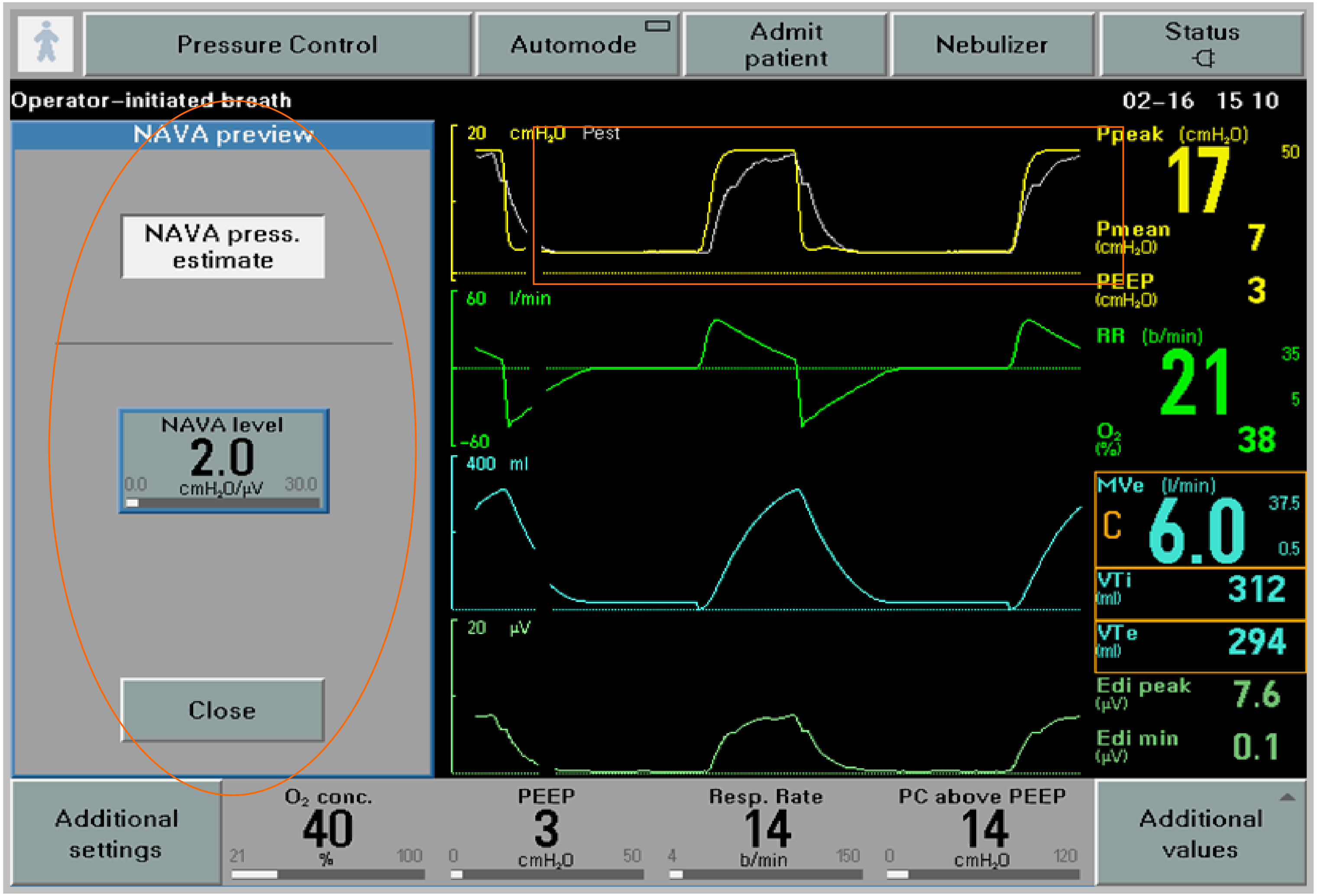
Position and Edi signal





連接Edi catheter及Edi module，並觀察Edi波形是否出現

按下NAVA Preview設定NAVA level



選擇NAVA mode設定各項參數及backup功能

Potential benefit of NAVA

- NAVA provides a lung protective mode of ventilation in spontaneous breathing.
- NAVA level titration can help determine adequate respiratory unloading.
- NAVA can facilitate physiological weaning.
- NAVA can be used to ensure that sedation can be maintained during spontaneous breathing.
- Improve patient and ventilator synchrony, reduce sedation.
- May reduce diaphragm disuse atrophy.
- Synchrony improves quality of sleep.

Ventilator Setting in Clinical Practice

Disease	Condition
ARDS	Low tidal volume, high PEEP, lower transpulmonary pressure
Brain edema	$PaCO_2$ 28-32 mmHg, careful use of PEEP
Restrictive lung disease (intrapulmonary)	V_T 7-10 ml/kg, higher rate
Restrictive lung disease (extrapulmonary) - high pleural pressure	V_T 12-15ml/kg (adequate Ptp)
Cardiogenic pulmonary edema	Moderate PEEP (8-10 cmH_2O)

Conclusions

- To evaluate lung mechanics in every mechanically ventilated patients: compliance, resistance, trans-pulmonary pressure
- To manage the interaction between MV and Patients
- To deliver disease-specified MV setting to reduce ventilator-induced lung injury
- To use new mode (dual mode, advanced close loop) for specific purpose in MV-patients