Physiology and Setting of MV

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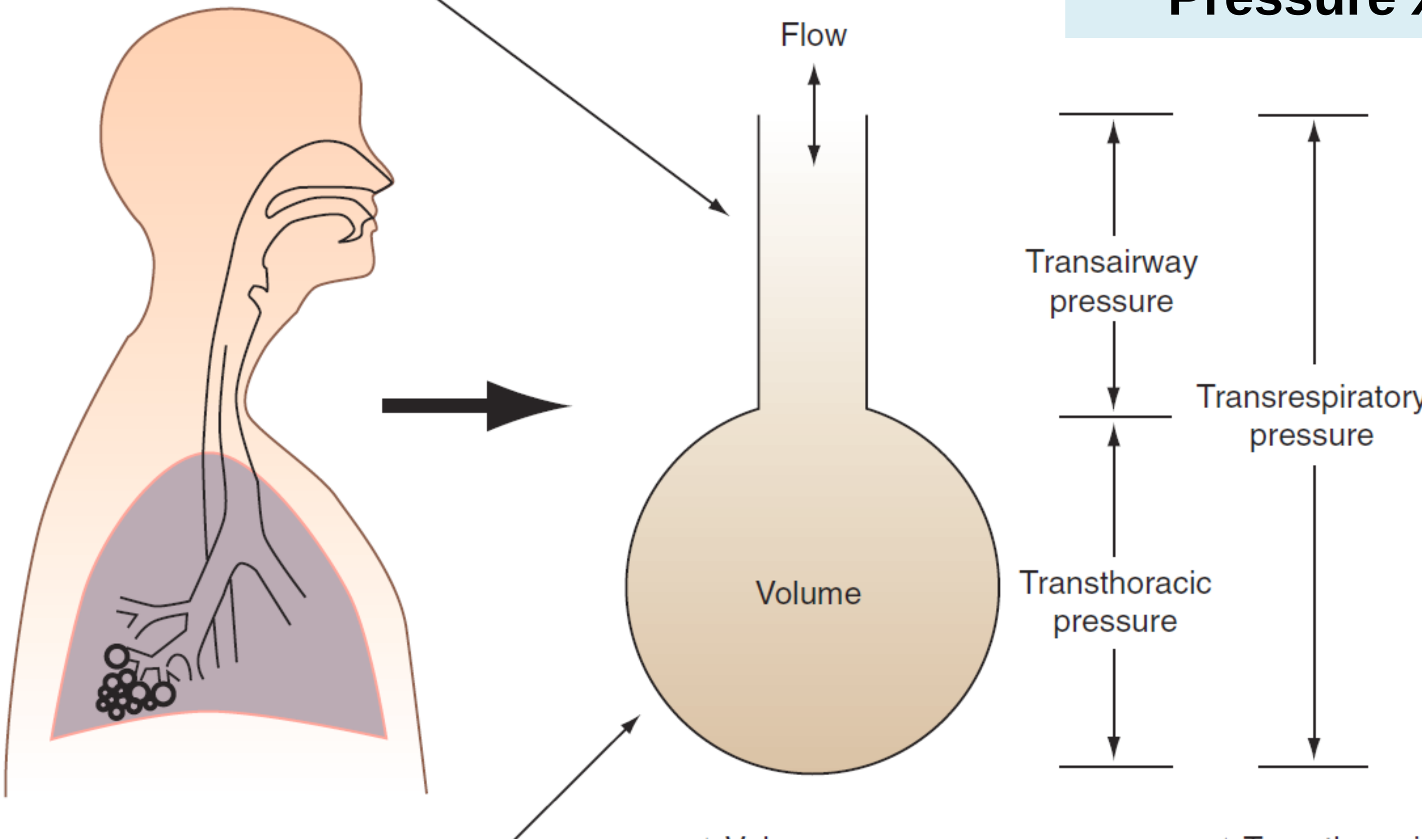
8:30-9:20 7 July 2019

Work of Breathing
Pressure x Volume

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

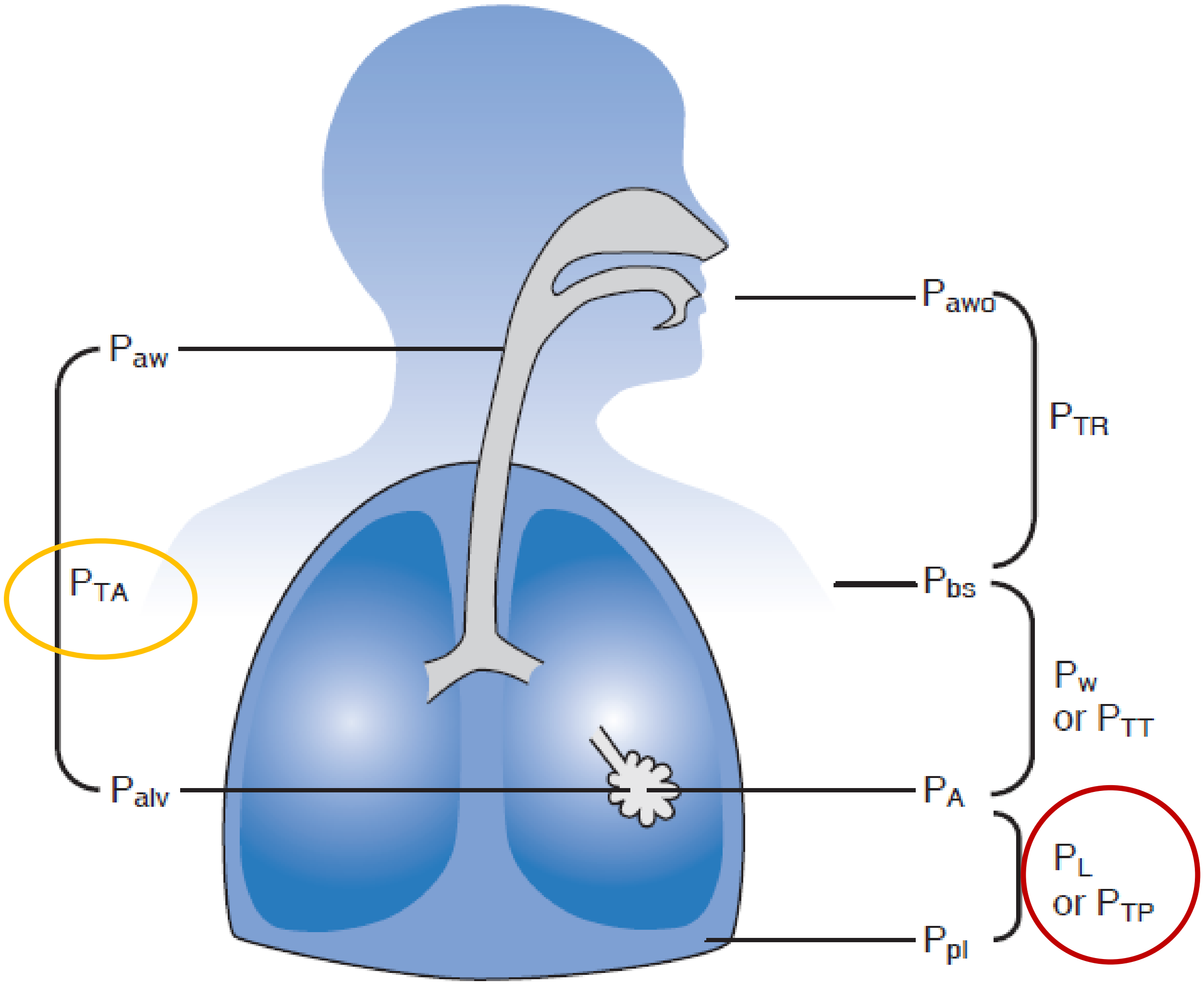


$$\text{Compliance} = \frac{\Delta \text{ Volume}}{\Delta \text{ Transthoracic pressure}}$$

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

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

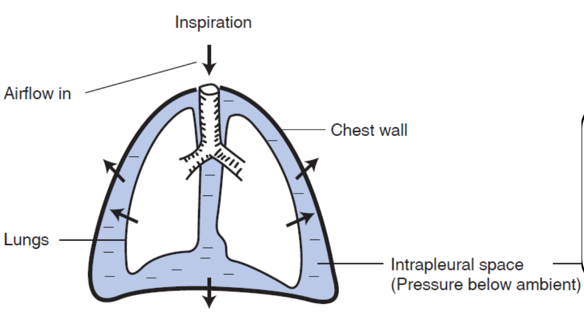
Volume Change

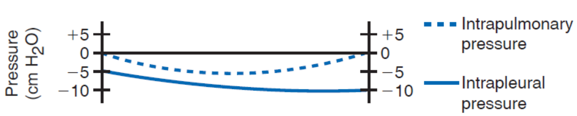
↓

Pressure Difference

↓

Gas Flow





Mechanical Ventilation

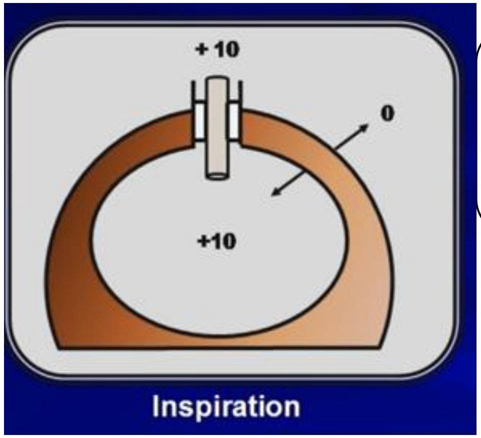
Pressure Difference

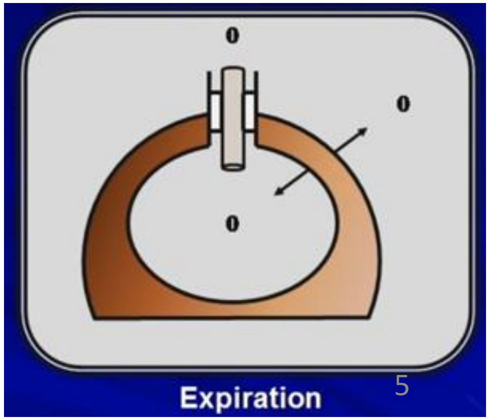
↓

Gas Flow

↓

Volume Change





Equation of Motion

DYNAMIC CHARACTERISTICS:
$dP = dV / Cdyn$

RESISTANCE:
$dPresistive = R \times Flow$

STATIC COMPLIANCE:
$dPdistensive = dV / Cst$

--Airway
--imposed

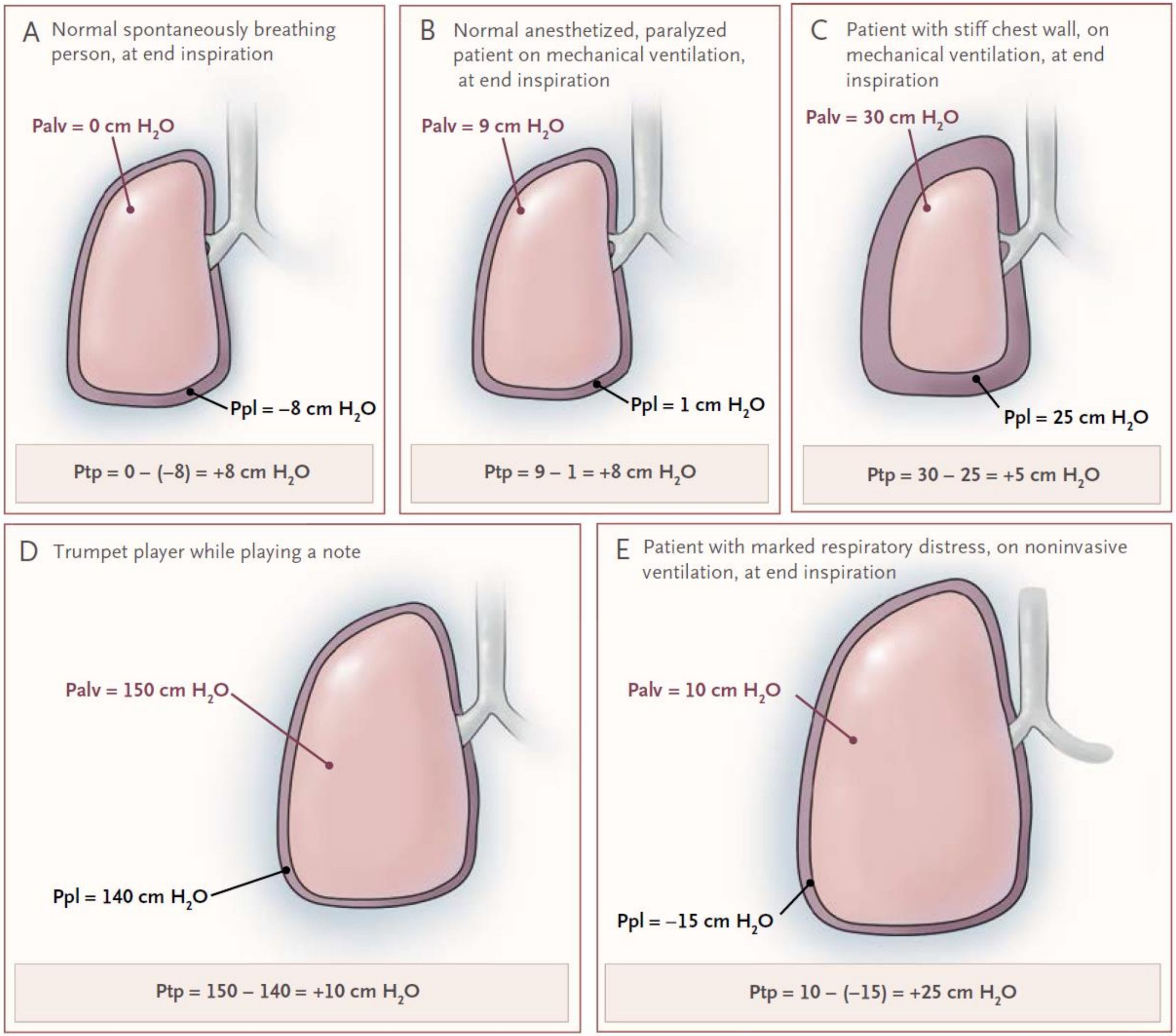
$$dP = dP_{resist.} + dP_{dist.}$$

--Lung
--Chest wall

$$dP = R \times Flow + dV / C\ st$$

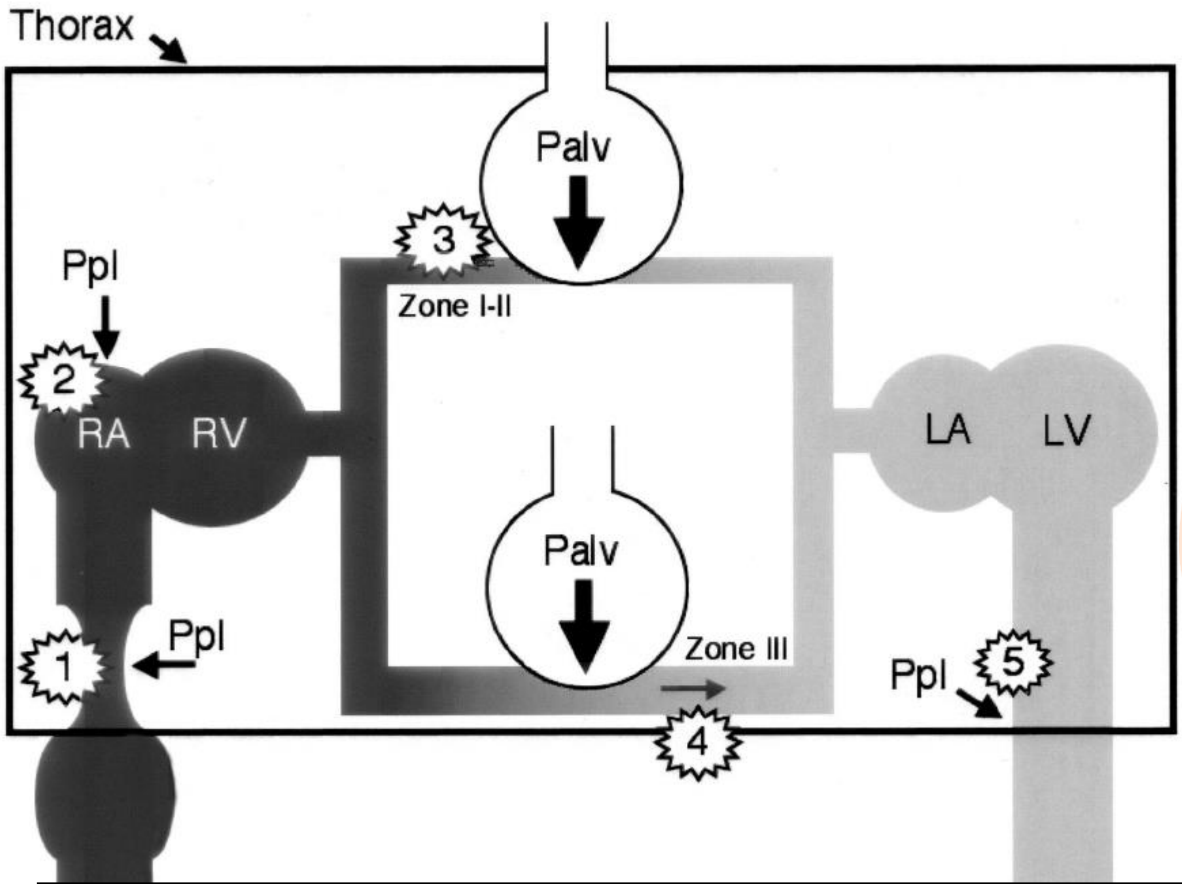
Pvent + Pmus
ventilator prpessure to deliver the volume

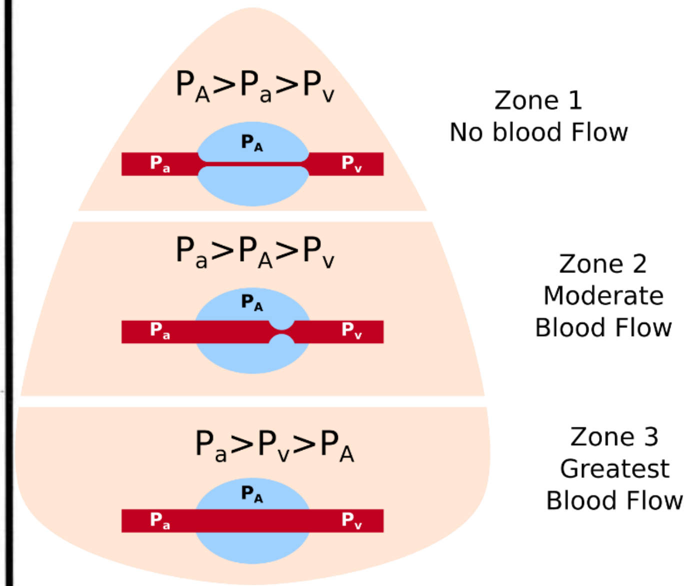
Transpulmonary pressure = Alveolar pressure – Pleural pressure



NEJM 2013; 369: 2126-2136

Physiologic effects of MV in hypovolemic conditions

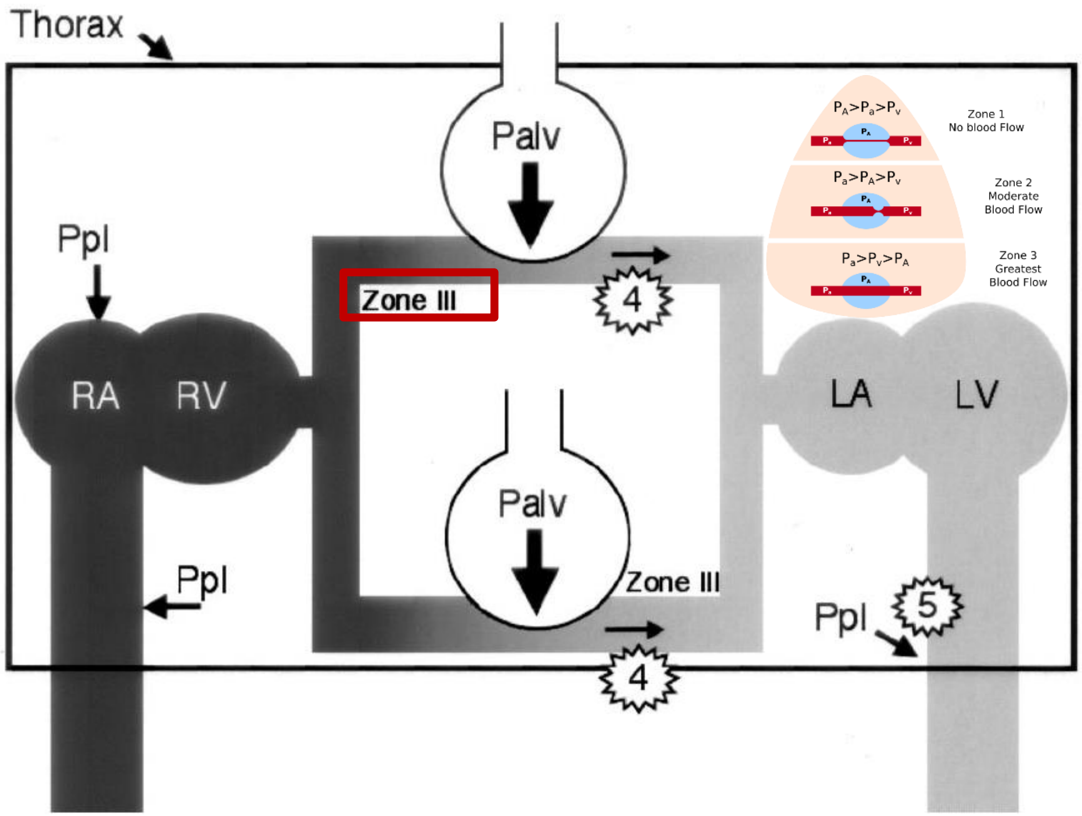




(1,2) RV preload decreases because the increase in pleural pressure induces a compression of the SVC and an increase in intramural RA pressure.
(3) In West zones I (pulmonary arterial pressure < alveolar pressure) and II (pulmonary venous pressure < alveolar pressure), RV afterload increases because pulmonary capillaries are compressed.
(4) In West zones III (alveolar pressure < pulmonary venous pressure), the increase in alveolar pressure squeezes out the blood contained in the capillaries toward the left side of the heart.
(5) The increase in pleural pressure induces a decrease in LV afterload.

Anesthesiology 2005;103:419-28

Physiologic effects of MV in hypervolemic conditions

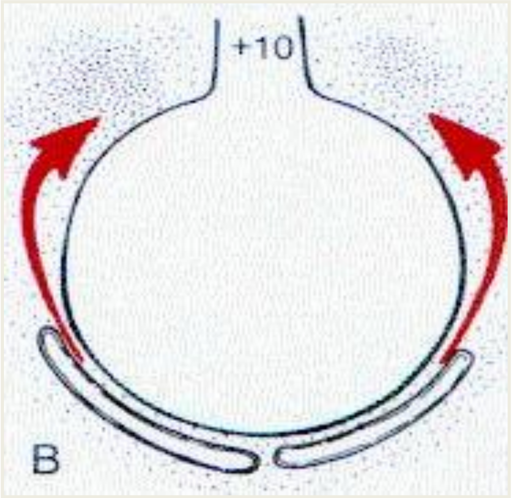


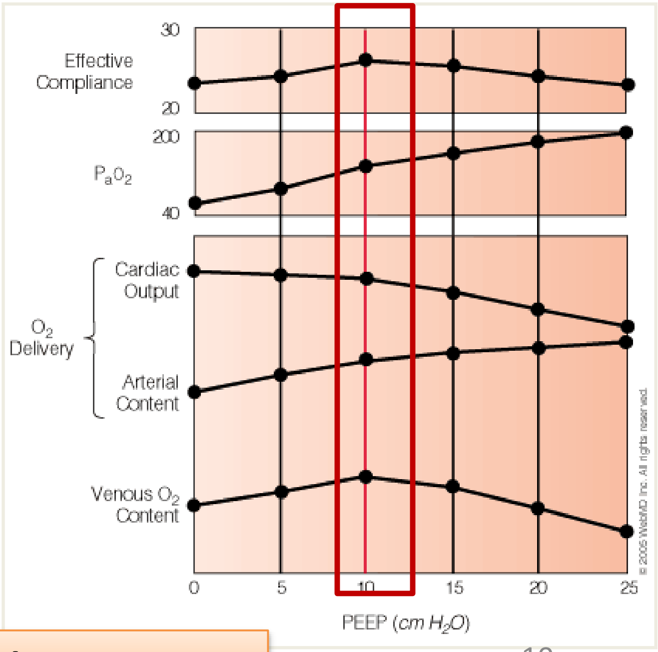
The vena cava and right atrium are poorly compliant and compressible and hence relatively insensitive to changes in pleural pressure.
(4) West zones III (alveolar pressure < pulmonary venous pressure) are predominant in the lungs such that each mechanical breath increases pulmonary venous flow and left ventricular preload.
(5) The increase in pleural pressure induces a decrease in left ventricular afterload.

Anesthesiology 2005;103:419-28

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

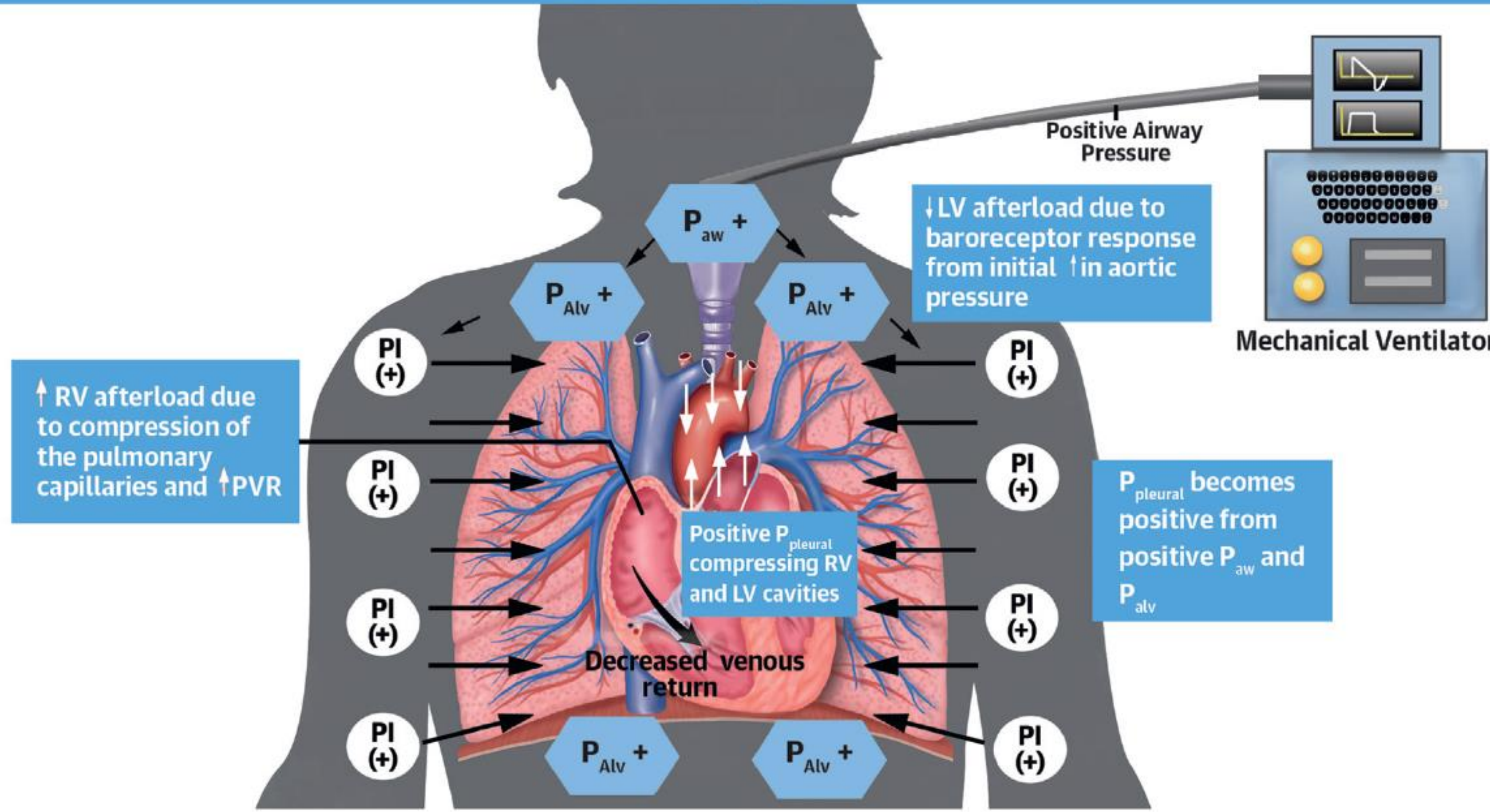




Oxygen delivery (DO_2), not PaO_2, should be used to assess optimal PEEP.

A. Postive Pressure Ventilation

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



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

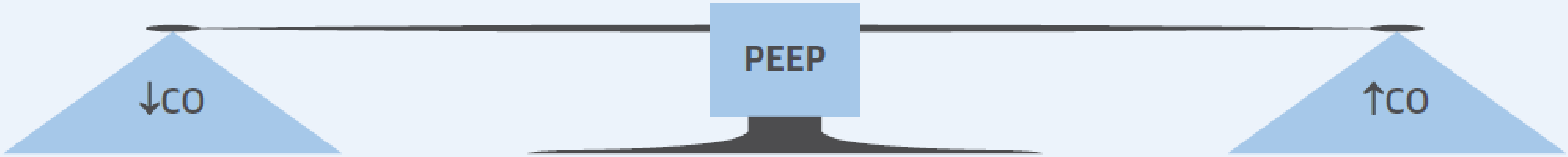
Potential physiologic effect of PEEP on ventricular function and cardiac output

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

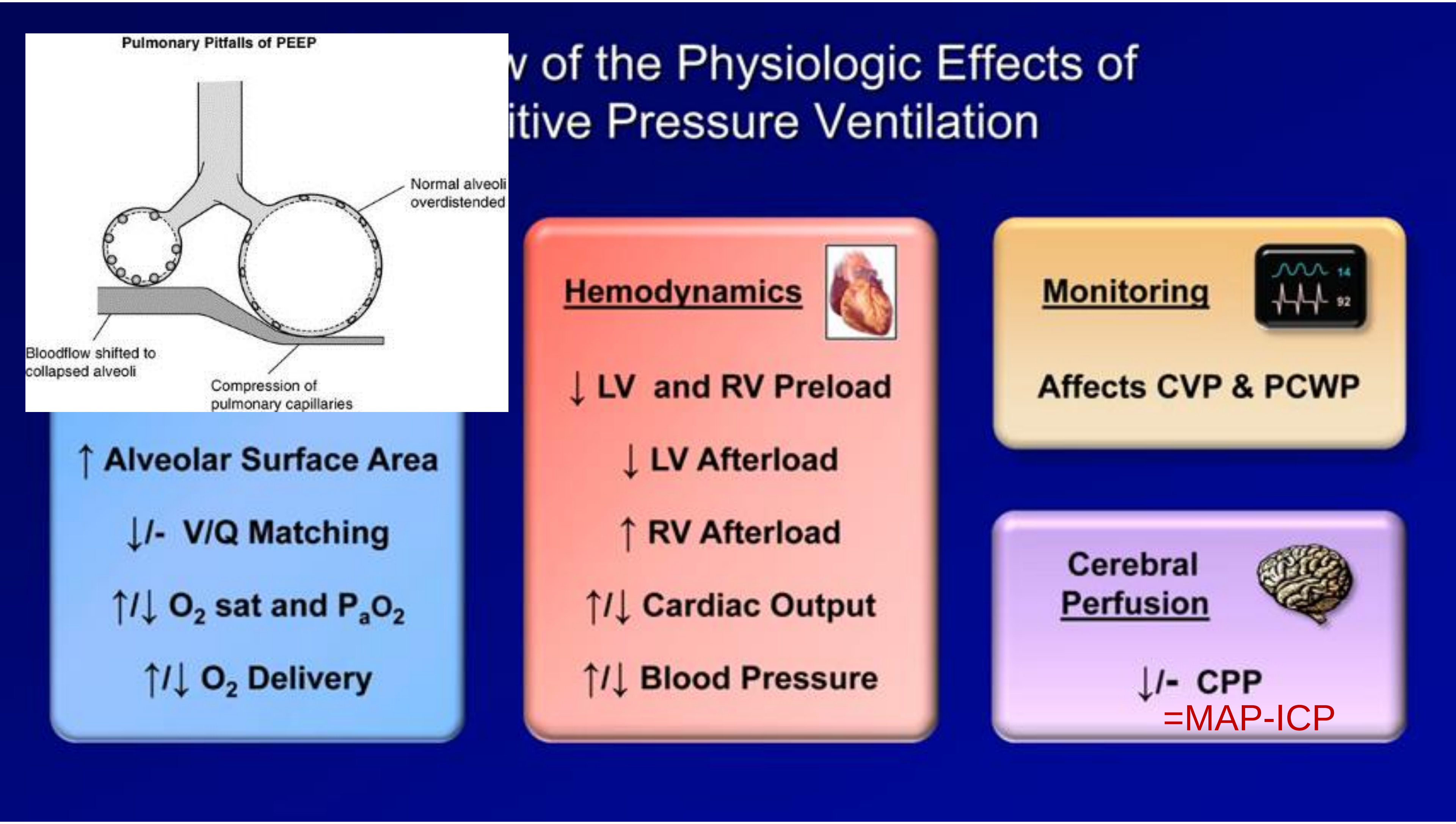
- ⬇ Preload due to lower RV output
- ⬇ Stroke volume due to interventricular dependence
- ⬇ Left ventricular (LV) afterload
- ⬇ LV preload and LV dilatation
- ⬇ Myocardial oxygen demand
- ⬆ Pressure gradient from thorax to periphery
- ⬆ Hydrostatic displacement of alveolar edema



Clinical Pearls

- Net effect of positive end-expiratory pressure (PEEP) on cardiac output (CO) depends on RV/LV function, preload, afterload, and ventricular interdependence.
- In RV failure/preload dependence, moderate to high PEEP (5-15 cmH_2O) may decrease RV CO.
- In afterload dependent states (e.g., LV failure), moderate to high PEEP (10-15 cmH_2O) may improve CO.

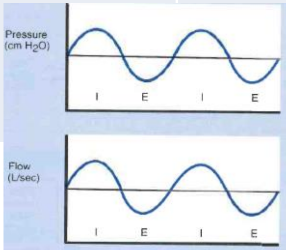
J Am Coll Cardiol 2018;72:1532-53



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

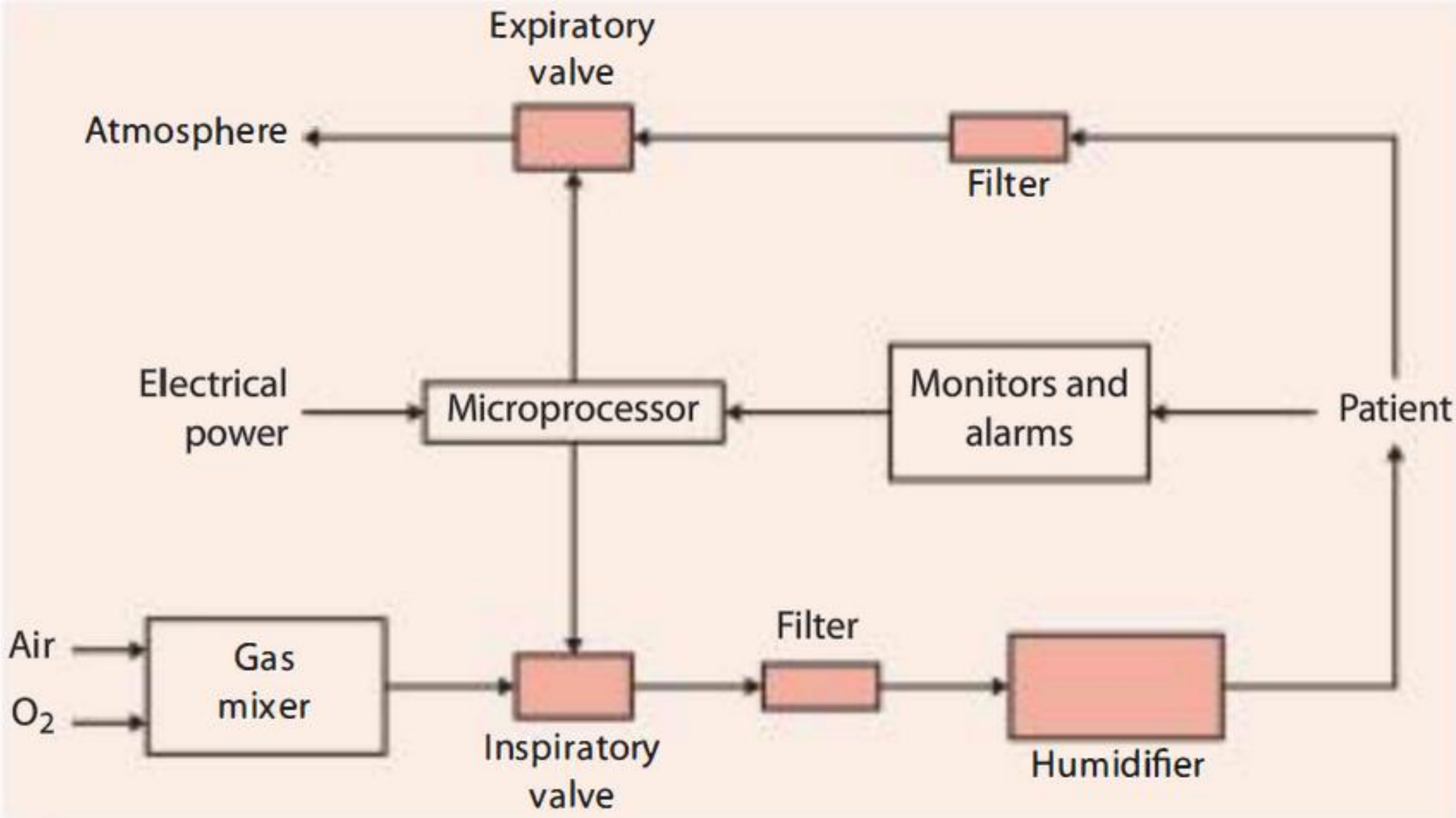
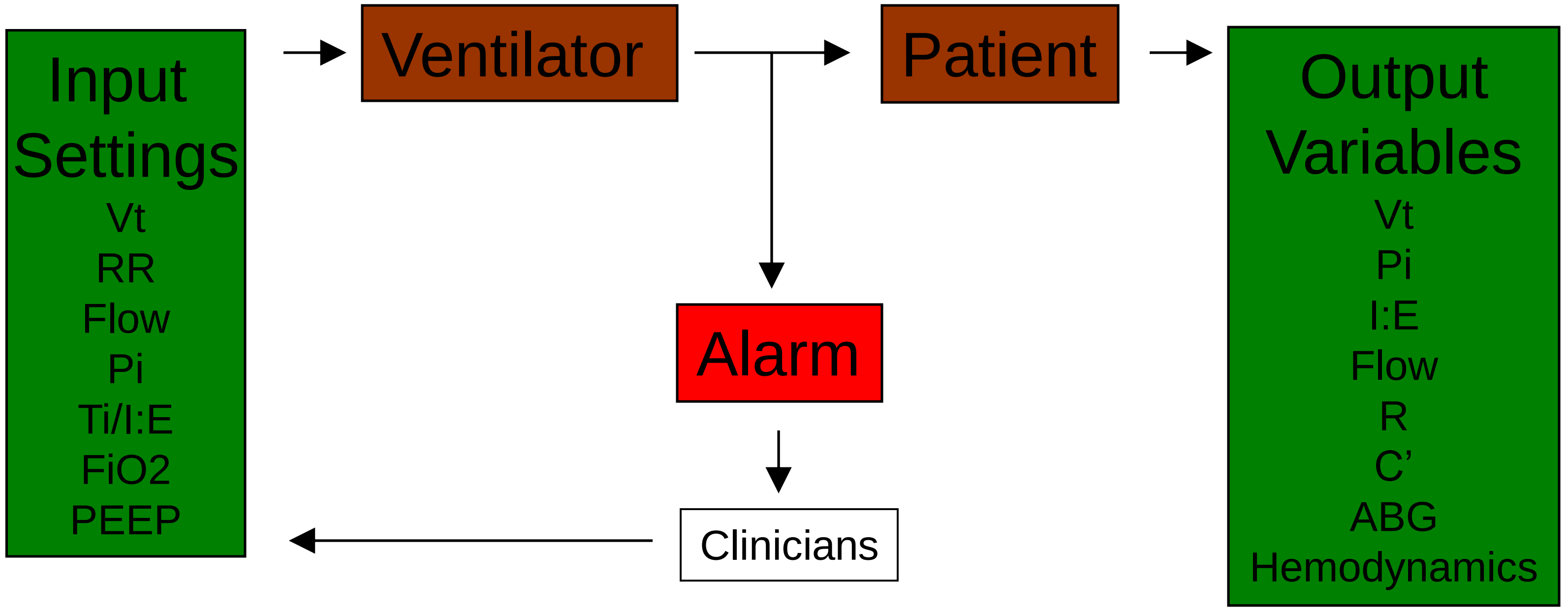


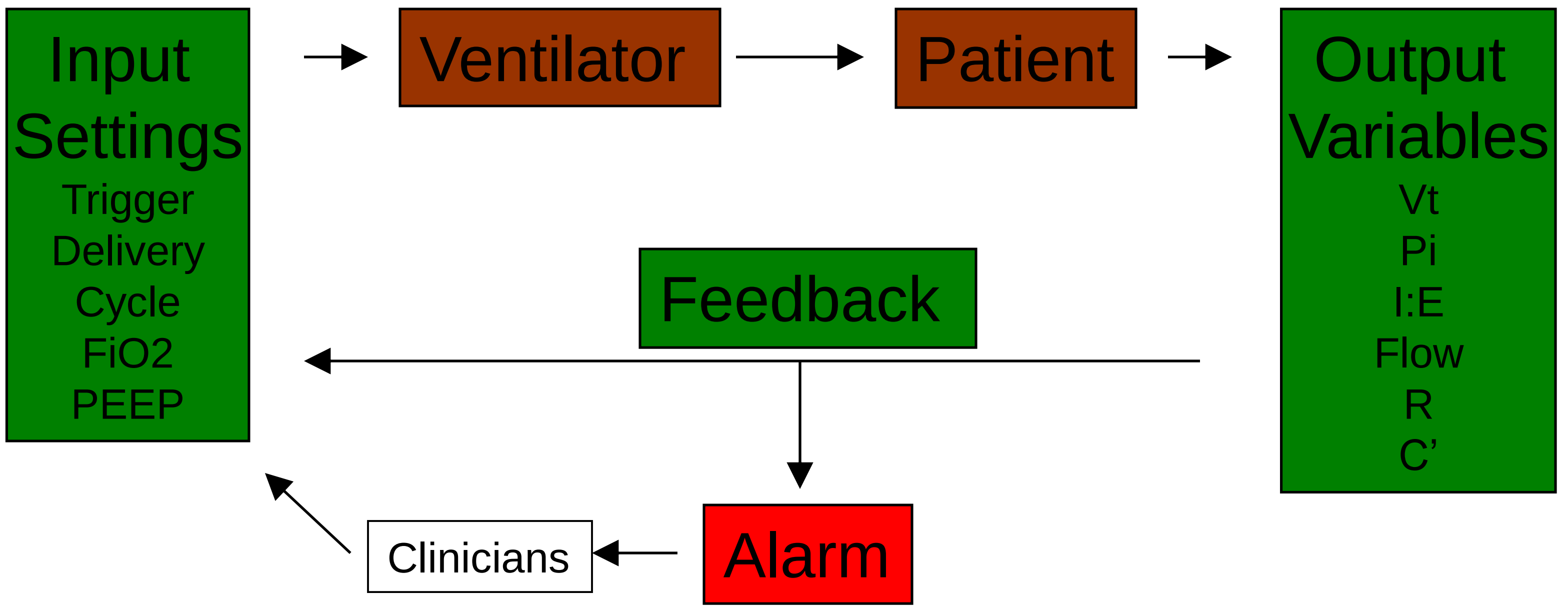
Figure 5-1 A simplified generic block diagram of the ventilator system.

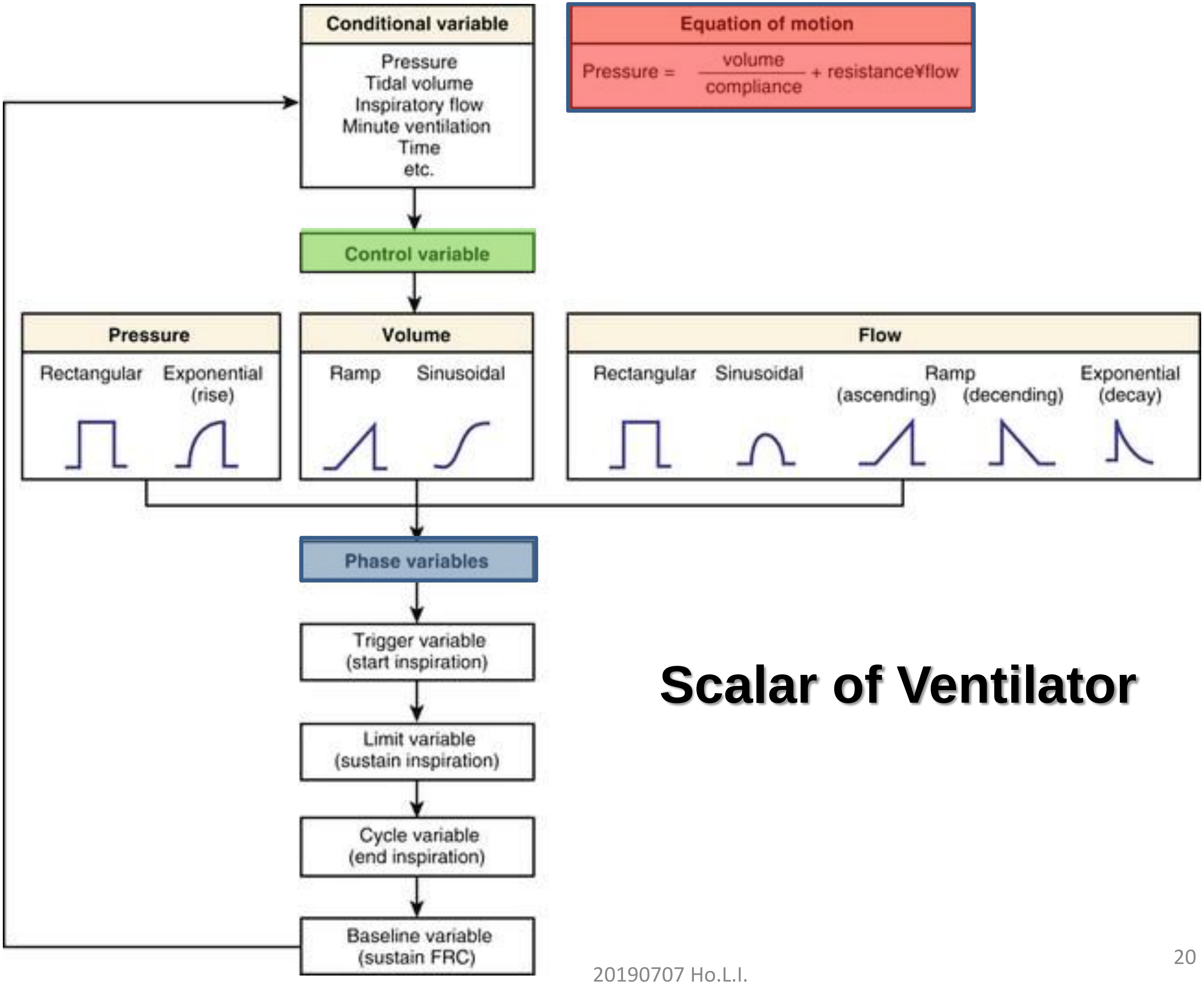

5
graphics
4
Mode
2
IPPV
1
electrical
3
Control system, User interface, Circuit

Open-Loop Control



Closed-Loop Control
servo control

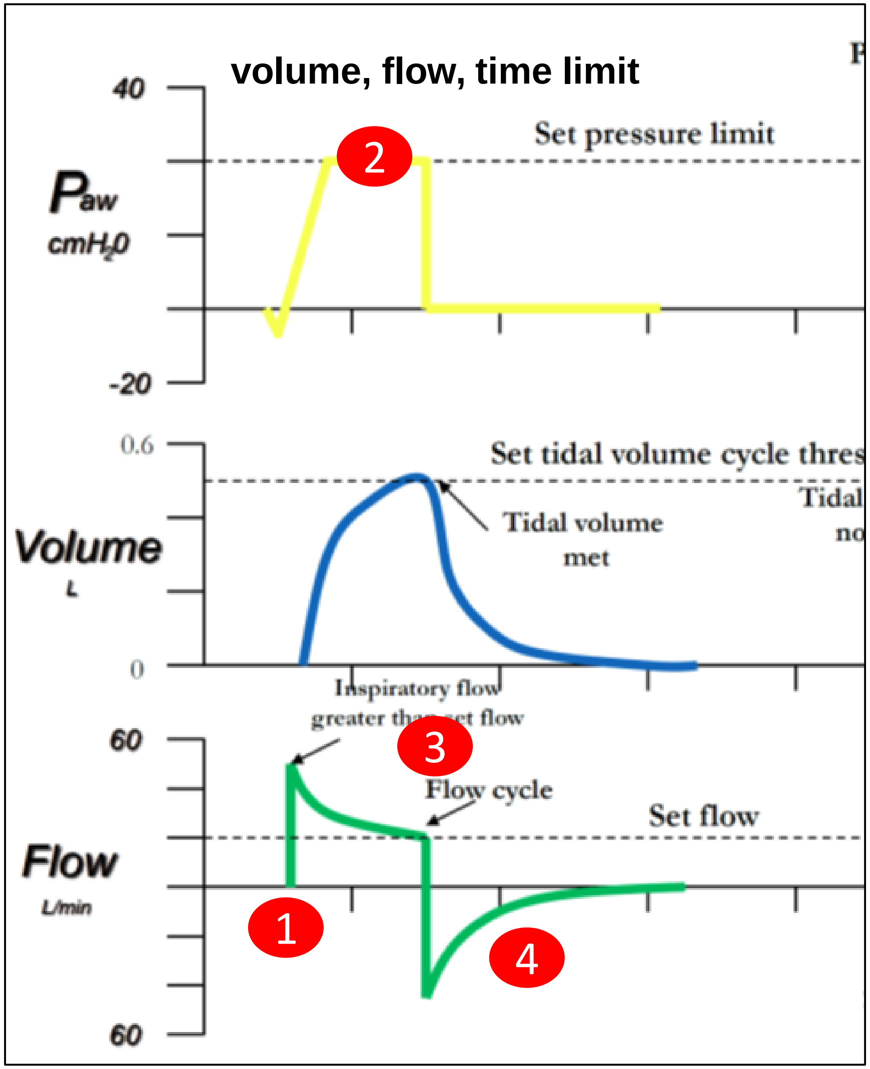




Scalar of Ventilator

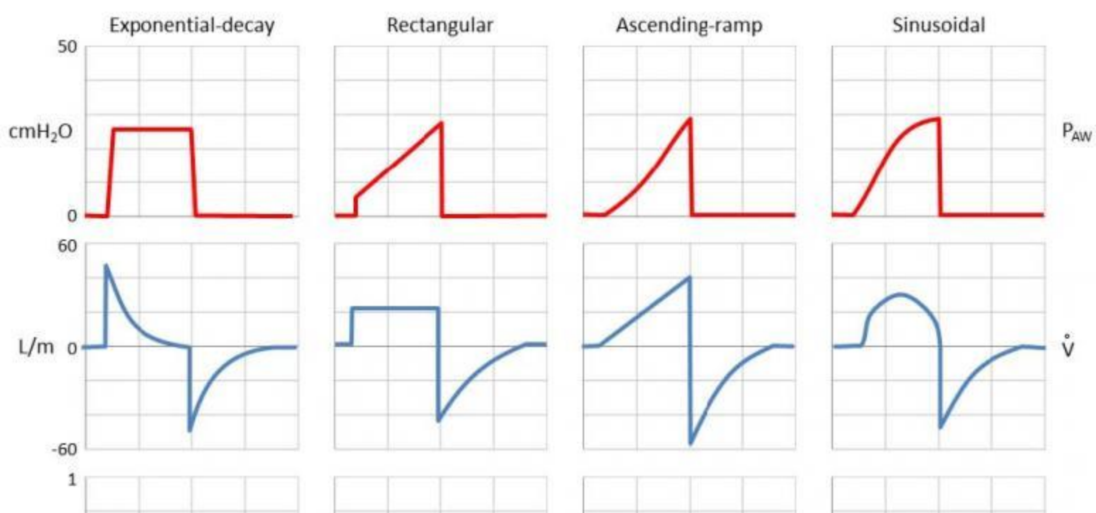
Four Phases of a Breath

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) 吸氣變為吐氣
4. Expiratory phase



Initial Ventilator Setting: principle

- Mode selection
- FiO2 = 21-100% (<60%)
- Vt= 8-10 ml/kg, (ARDS 6 ml/IBWkg 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)



Ventilator Setting: triggering/cycling

- Humidify : 34-37℃
- **Inspiratory sensitivity**:
  - Pressure trigger
  - Flow trigger
  - Time trigger
  - Volume trigger
  - Edi trigger
  - Impendence
- Cycle (expiratory trigger sensitivity, ETS): determine the end of inspiration.

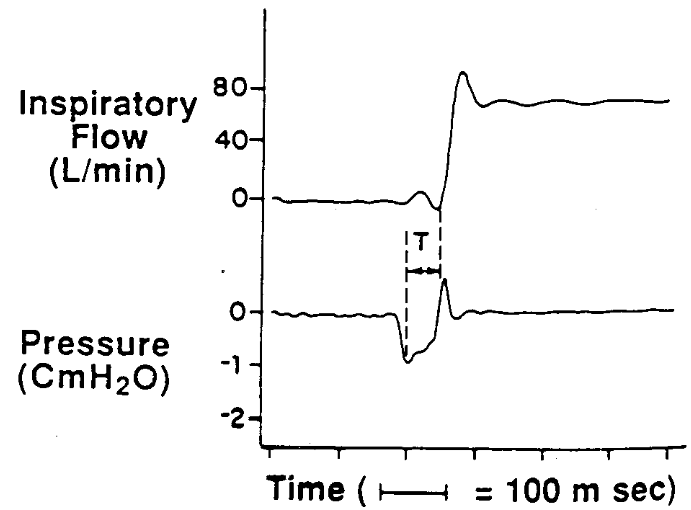
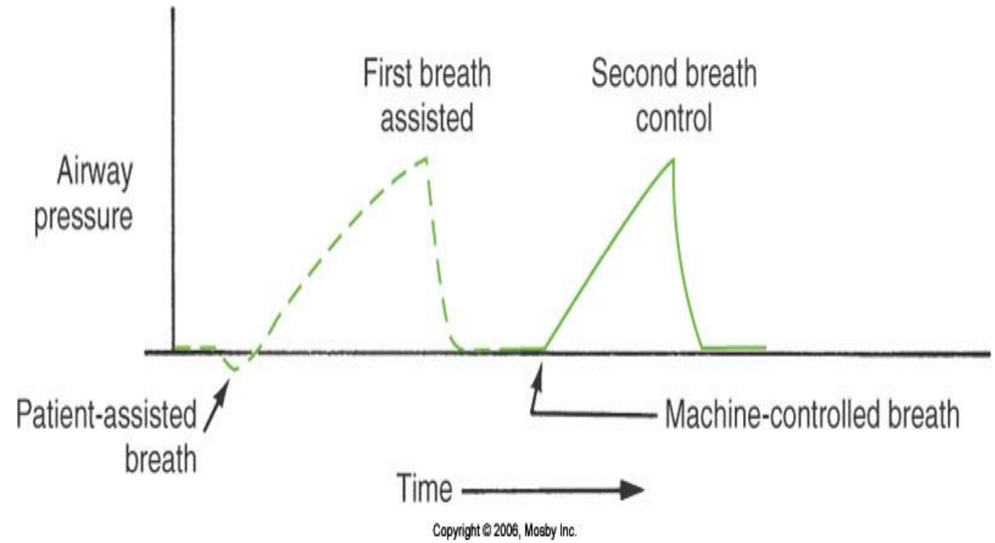


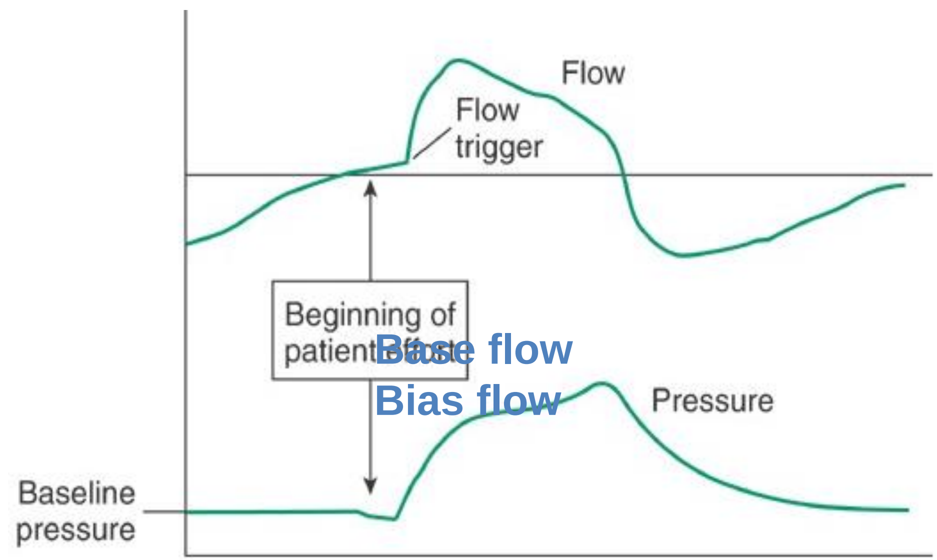
Fig. 30-5 Tracing of pressure and flow during initiation of a pressure-triggered mechanical breath. Sensitivity is measured as the pressure drop needed to initiate flow, in this case about 1 cm H_2O. Response time (T) is measured as the time interval between this 1 cm H_2O pressure drop and the actual start of flow, here about 70 msec. (From: Capps JS, Ritz R, Pierson DJ: An evaluation in four ventiiators, of characteristics that affect work of breathing, *Respir Care* 32(11):1017-1024, 1987.)

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



Base flow
Bias flow

Ventilator Setting: limit for alarm

- Limit
  - high pressure alarm (PIP + 10 cmH2O)
  - low pressure limit (10cm H2O)
- Low minute ventilation (RR x Vt, >3L/min)
- PEEP
- Tidal volume (5ml/IBWkg acceptable)

Standard Modes of Ventilation

Full Support

PCV

ACV

Partial Support

SIMV

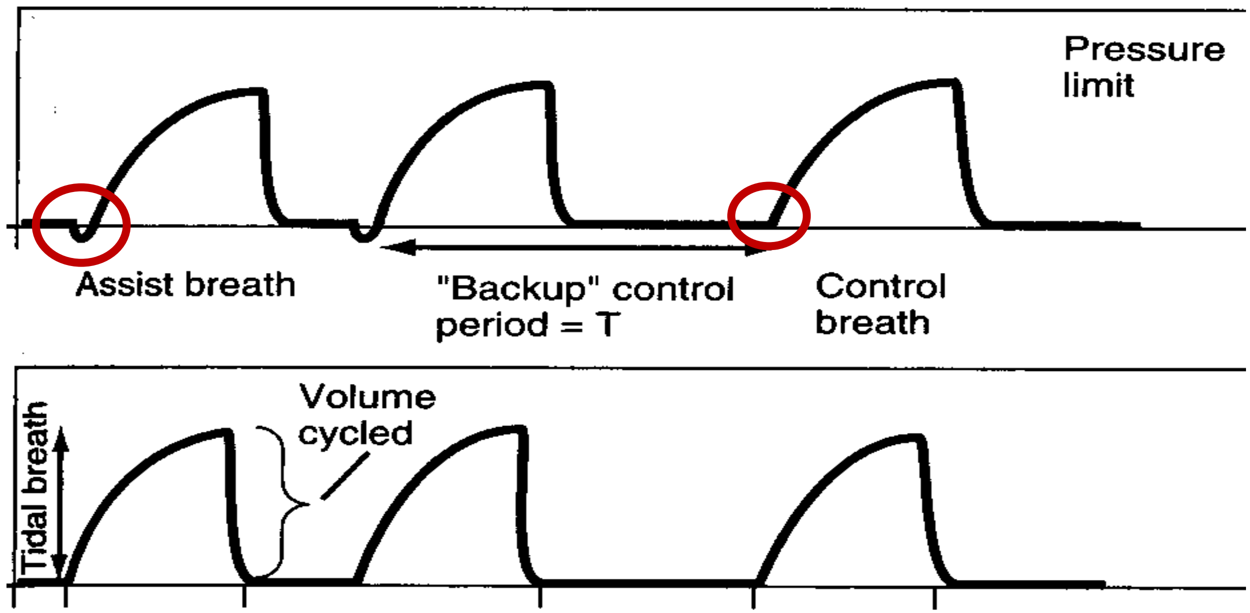
PS

Spontaneous Breathing

CPAP

Ventilator Mode: Assist-Control ventilation (ACV)

- Patient inspiratory effort or ventilator timer (Pressure-limit and volume-cycled) .
- Indications :for Paralyzed patient or needing total support, in patients need stable Vt



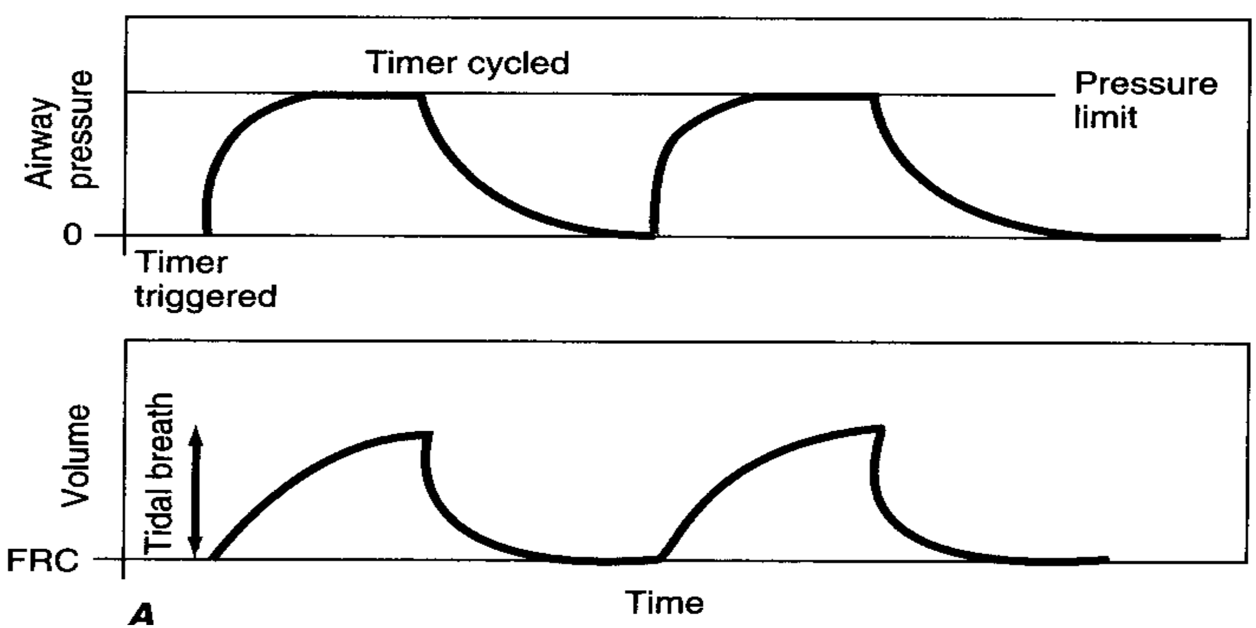
- Complications : (1) tachypnea with respiratory alkalosis . (2)auto-PEEP. (3)high pressure (must set high pressure limit)

TABLE 4-3 Characteristics of the Assist/Control Mode

Characteristic	Description
Type of breath	Each breath, assist or control, delivers a preset mechanical tidal volume.
Triggering mechanism	Mechanical breaths may be either patient-triggered (assist) or time-triggered (control).
Cycling mechanism	Inspiration is terminated either by the delivery of a preset tidal volume (volume-cycled) or by the high pressure limit (pressure-cycled).

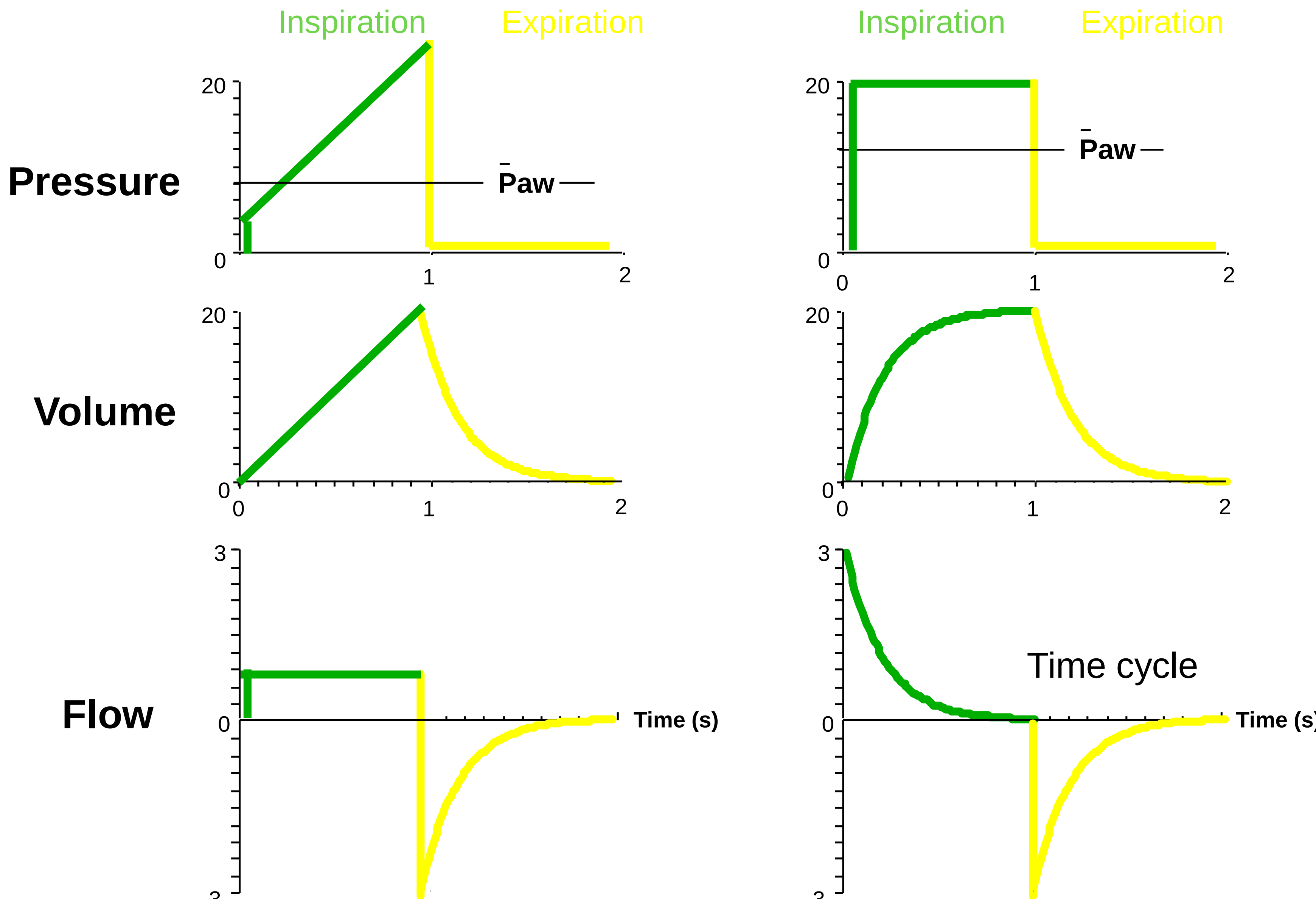
Ventilator Mode: Pressure-Target Ventilation (PACV, PCV)

- Timer triggered, timer cycled (Ti) and pressure limited .
- Indications: high PIP or barotrauma (e.g. PNX), post-op thoracic surgical patient ,hypoxemia.



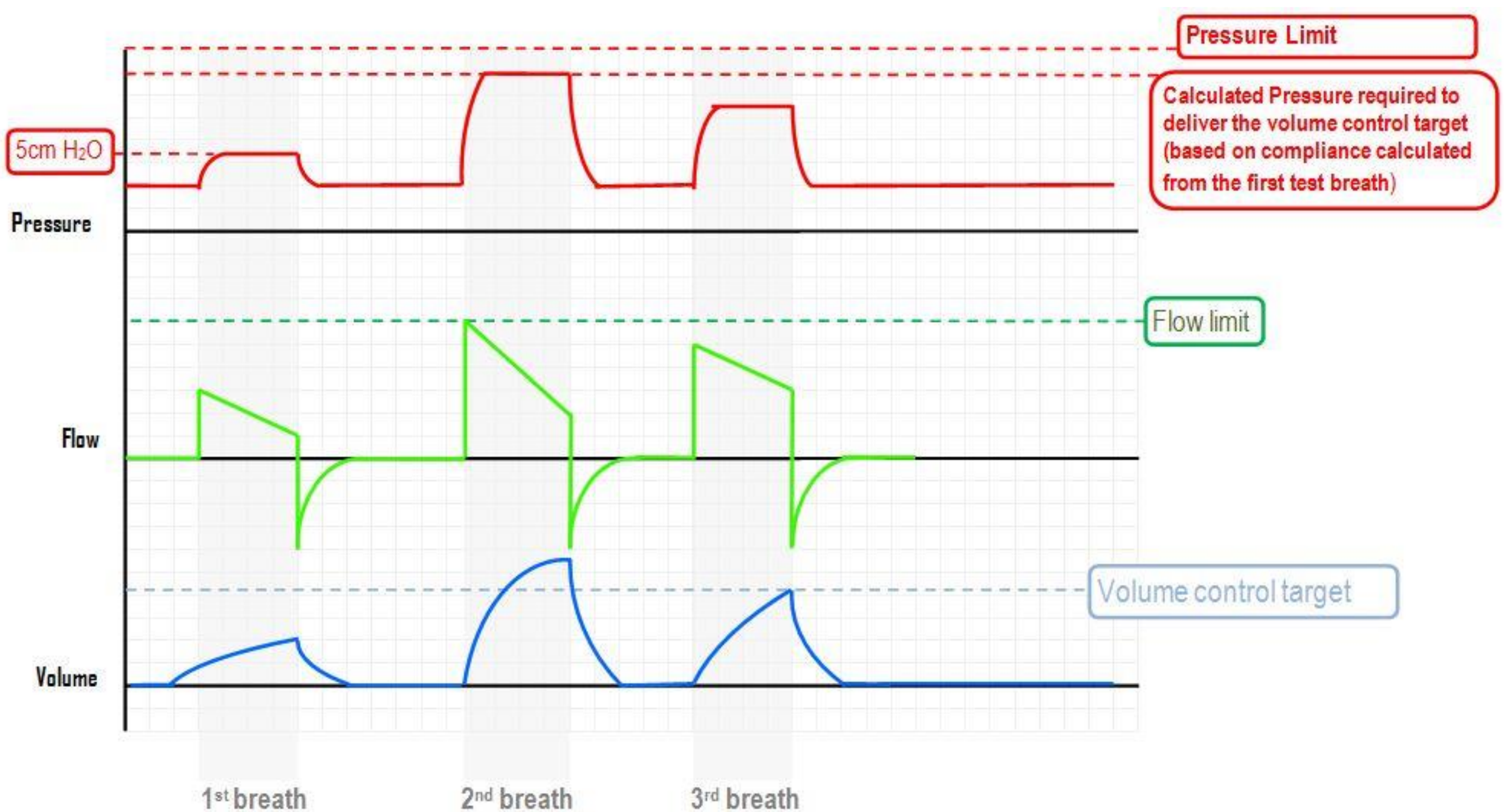
- Complications: variable tidal volume and minute ventilation, heavy sedation, permissive hypercapnia.

Volume/Flow Control   Pressure Control



Ventilator mode: PRVC (adaptive) pressure regulated volume control

- Time or patient triggered, time cycled, use the set Vt as a feedback control



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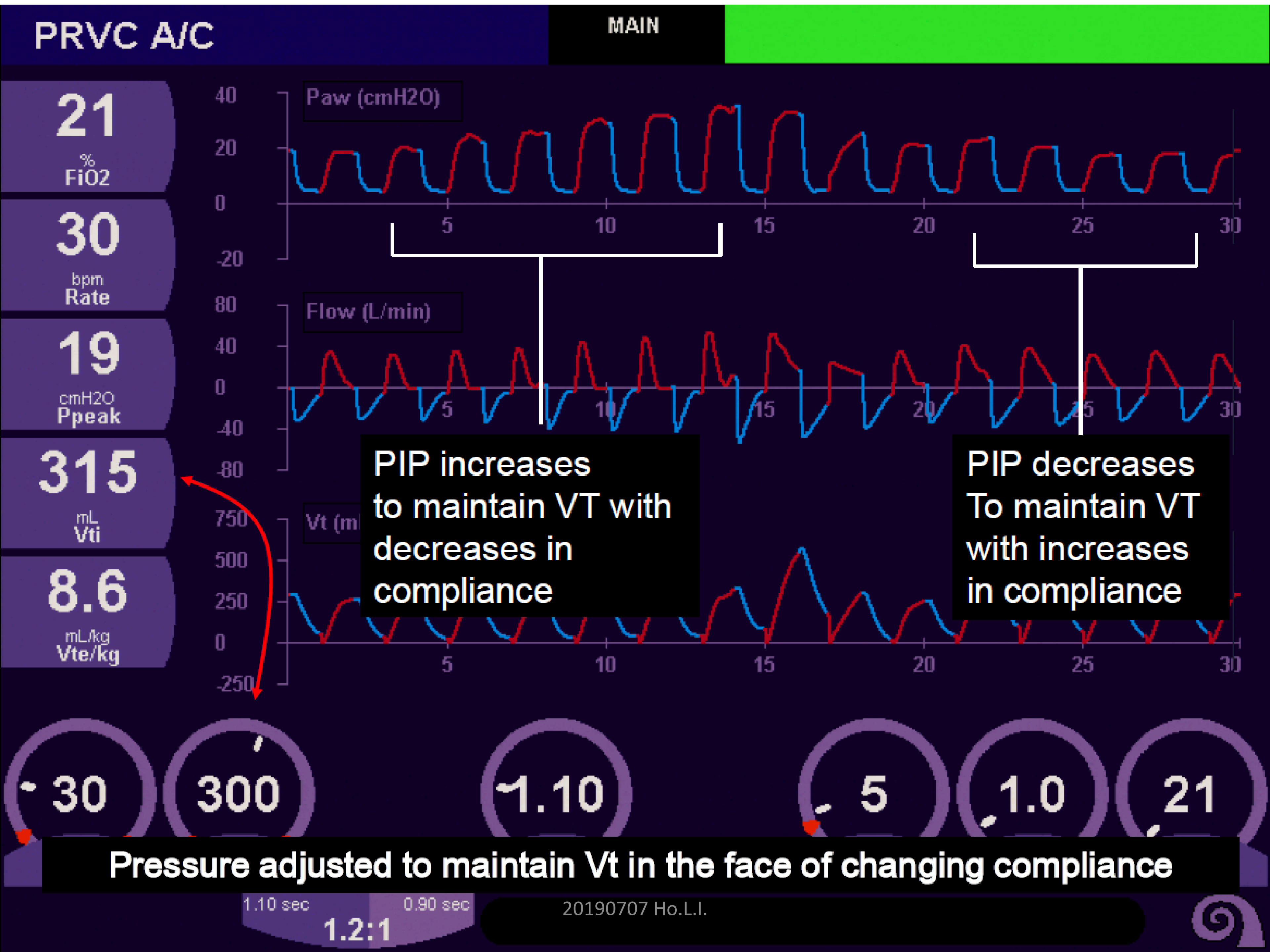
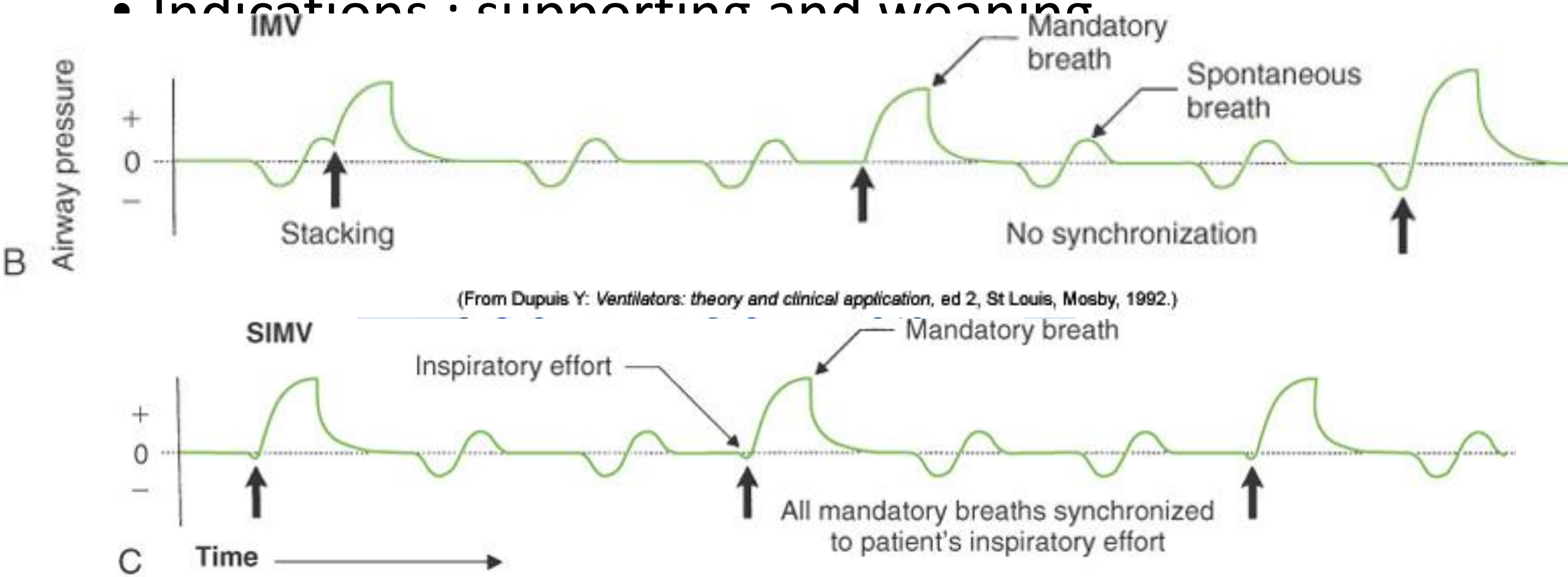

PRVC A/C
MAIN
21
% FiO2
30
bpm Rate
19
cmH2O Ppeak
315
mL Vti
8.6
mL/kg Vte/kg
Paw (cmH2O)
Flow (L/min)
PIP increases to maintain VT with decreases in compliance
PIP decreases To maintain VT with increases in compliance
30
300
1.10
5
1.0
21
Pressure adjusted to maintain Vt in the face of changing compliance
1.10 sec
0.90 sec
1.2:1
20190707 Ho.L.I.

Ventilator Mode:
Synchronized Intermittent mandatory ventilation (SIMV)

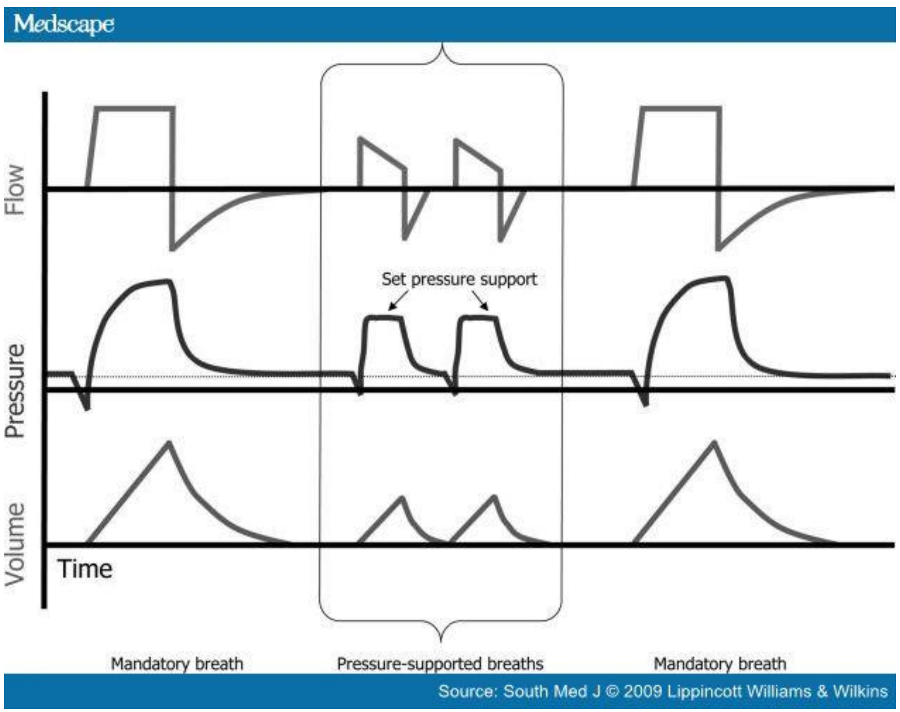
- Synchronized ventilator control (timer trigger, VAC/PCV).
- To prevents inadvertent stacking of a mechanical breath on top of a spontaneous inspiration.
- Indications : supporting and weaning

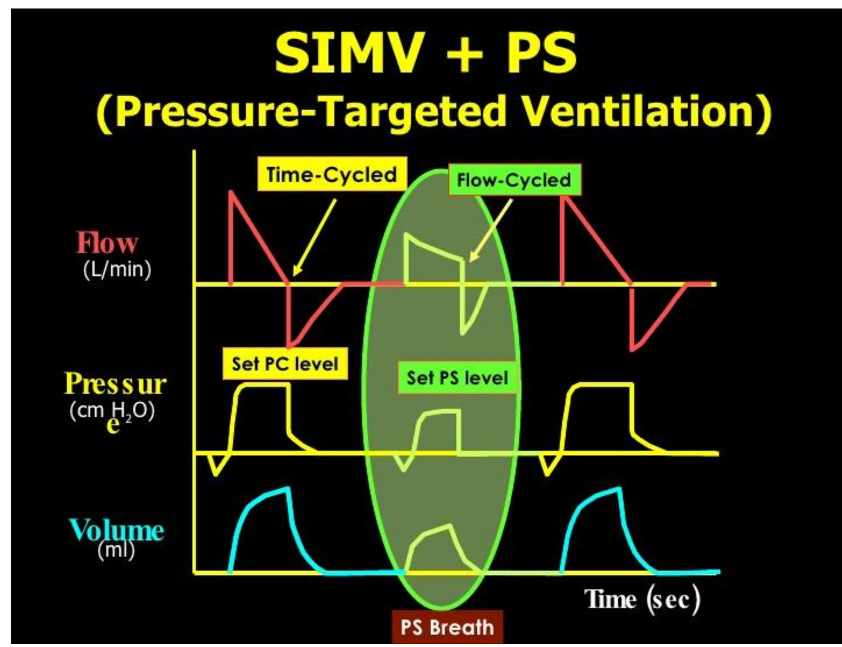


(From Dupuis Y: *Ventilators: theory and clinical application*, ed 2, St Louis, Mosby, 1992.)

(From Dupuis YG: *Ventilators: theory and clinical applications*, ed 2, St Louis, 1992, Mosby.)

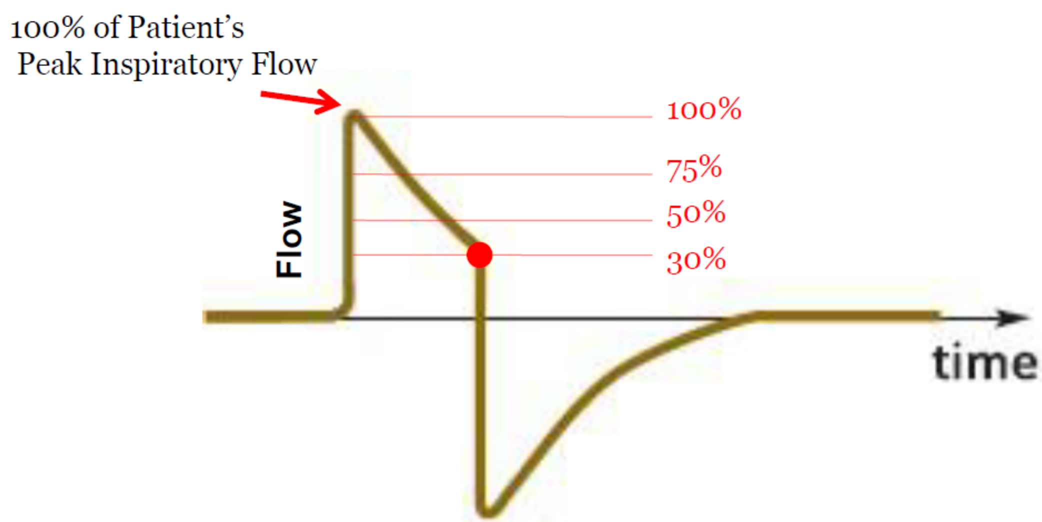
- **Diadavantages**:
  - tachypnea with aborted ventilation,
  - increase WOB
  - Lower C.O. in patients with LV dysfunction?





Inspiratory Cycle Off

- pati ... 25% flow
- Indi ... .



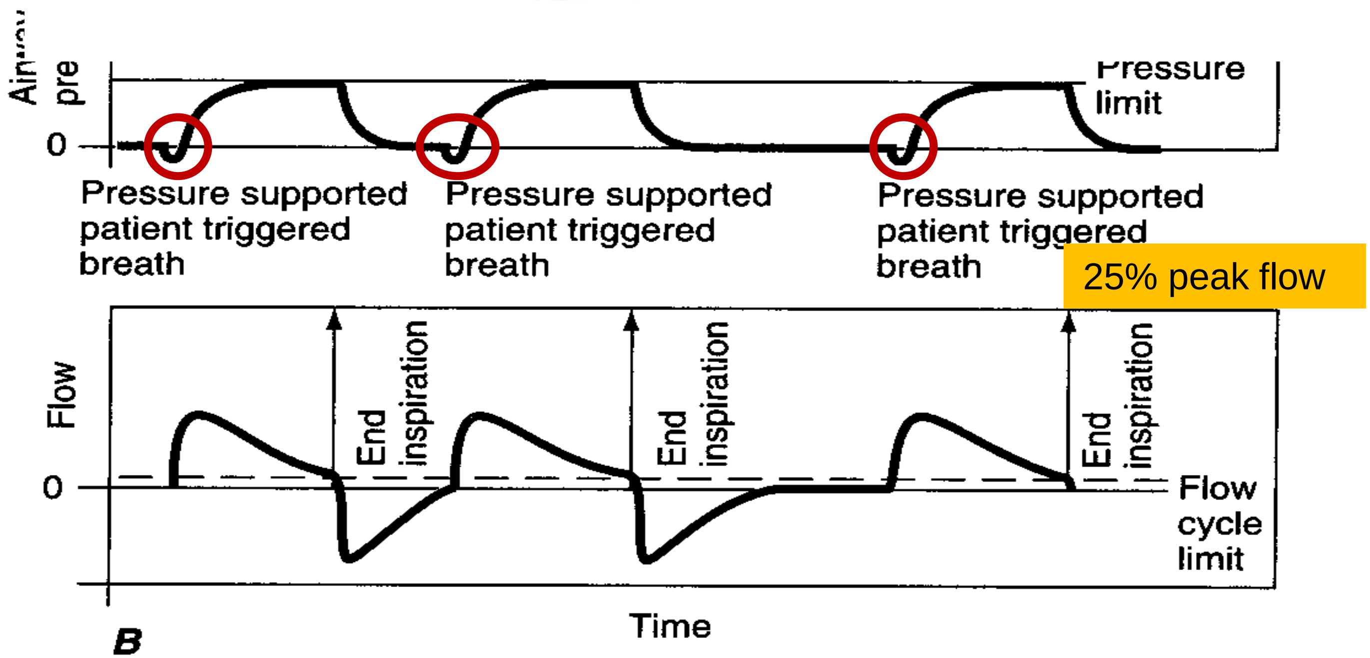


TABLE 5 Advantages and Disadvantages of PS Mode

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

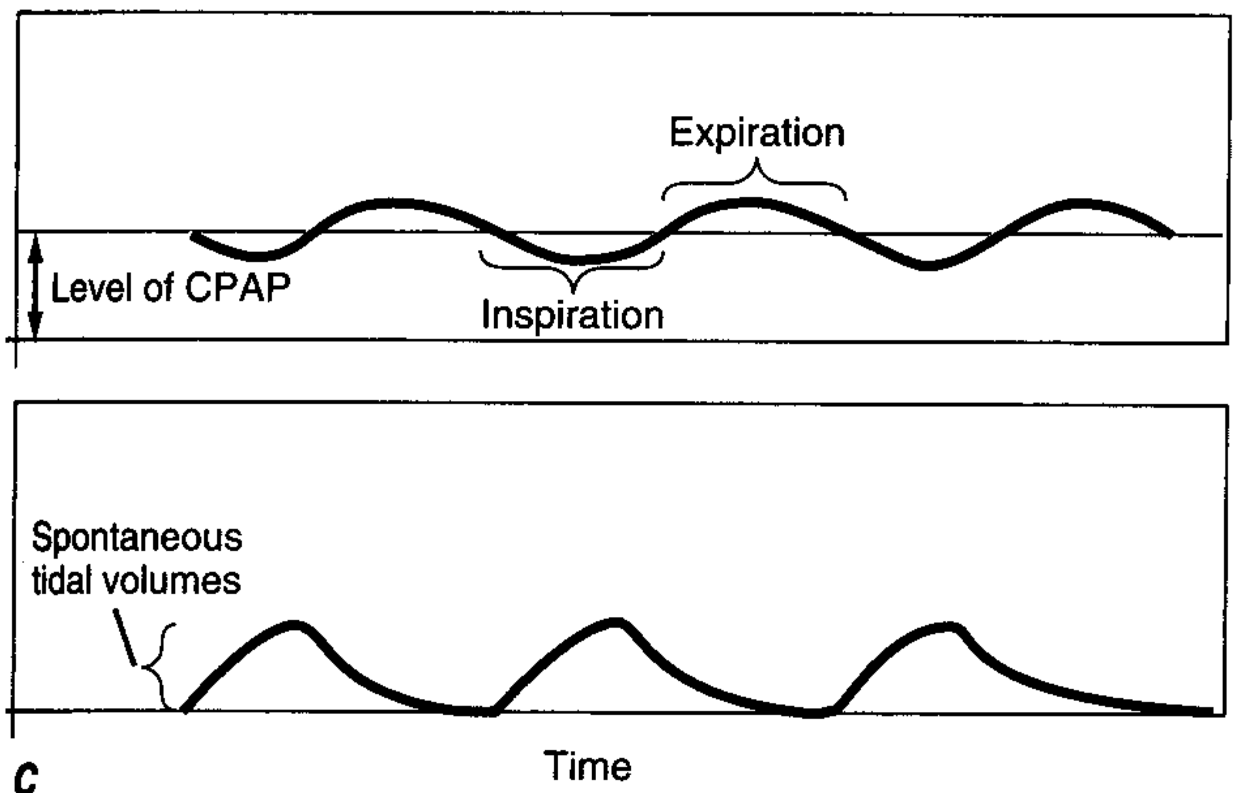
J Am Coll Cardiol 2018;72:1532–53

Mode variables

Variables	Common options	Typical settings
Trigger	Time triggered	To provide RR of 12-20
	Flow triggered	2-3 L/min
	Pressure triggered	0.5-2 cmH2O
Control	Flow controlled	Indirectly set by Vt(6-10 ml/kg), RR, I:E
	Pressured controlled	To provide Vt of 6-8 ml/kg
Cycling	Flow cycled	<25% peak flow
	Volumne cycled	To provide Vt of 6-10 ml/kg
	Time cycled	To provide RR of 12-20

Ventilator Mode: Continuous Positive airway pressure (CPAP)

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

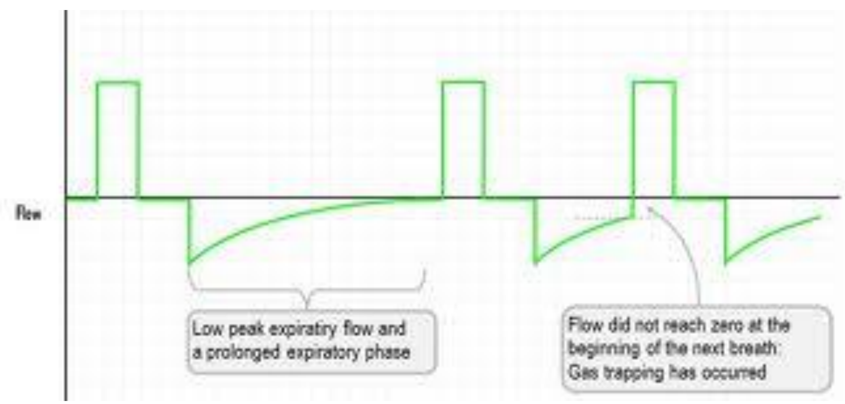


Single Modes

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

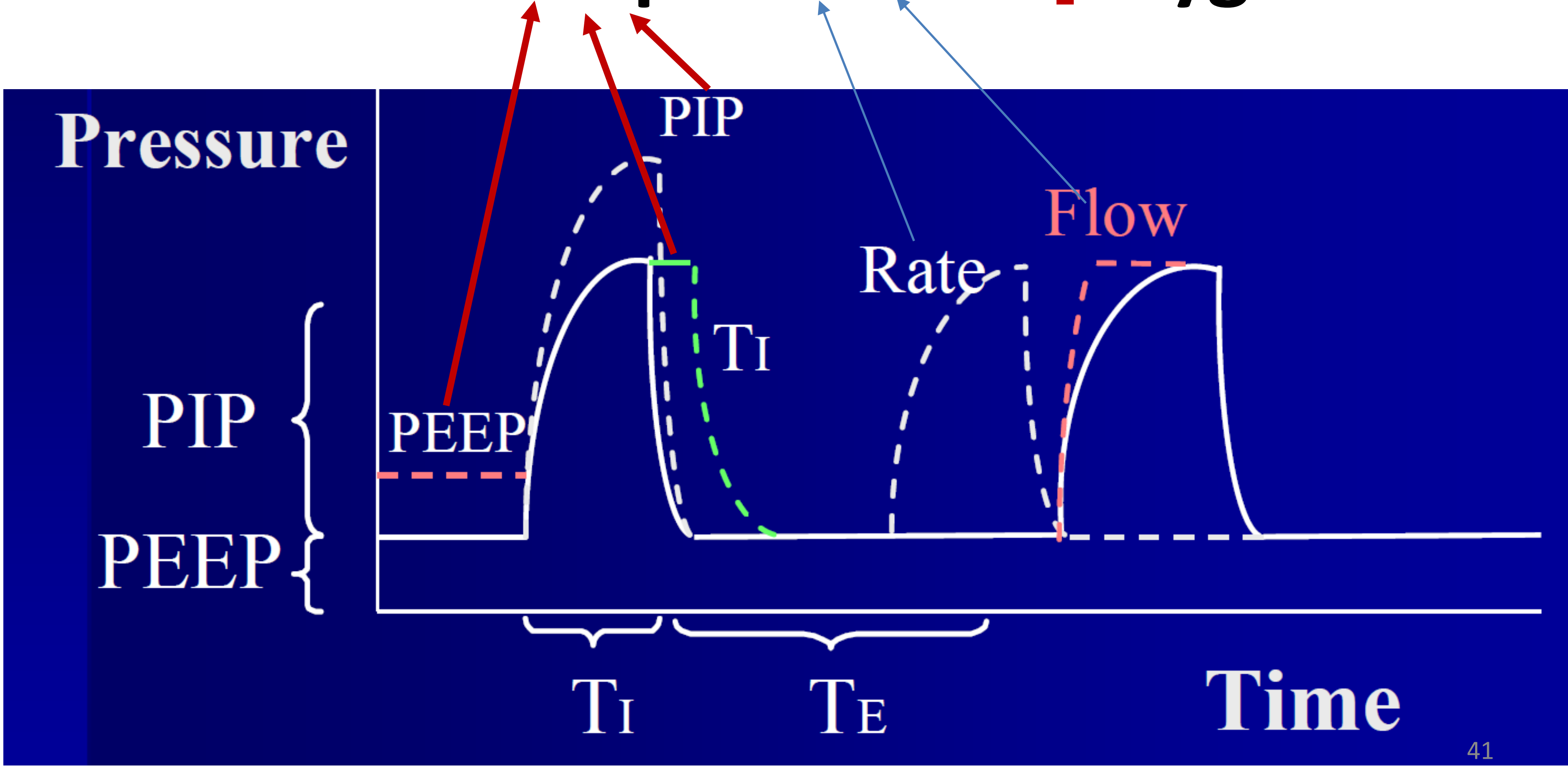
呼吸器設定

- CO_2 retention:
  - –PaCO2 和V_E(V_T X F)成反比
    - 增加V_T (Pplat<30)
    - 增加 f (<30 avoid PEEPi)
- 欲增加$PaCO_2$時：
    - 減少V_T
    - 減少 f
    - Add dead space



Factors increasing oxygenation

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



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

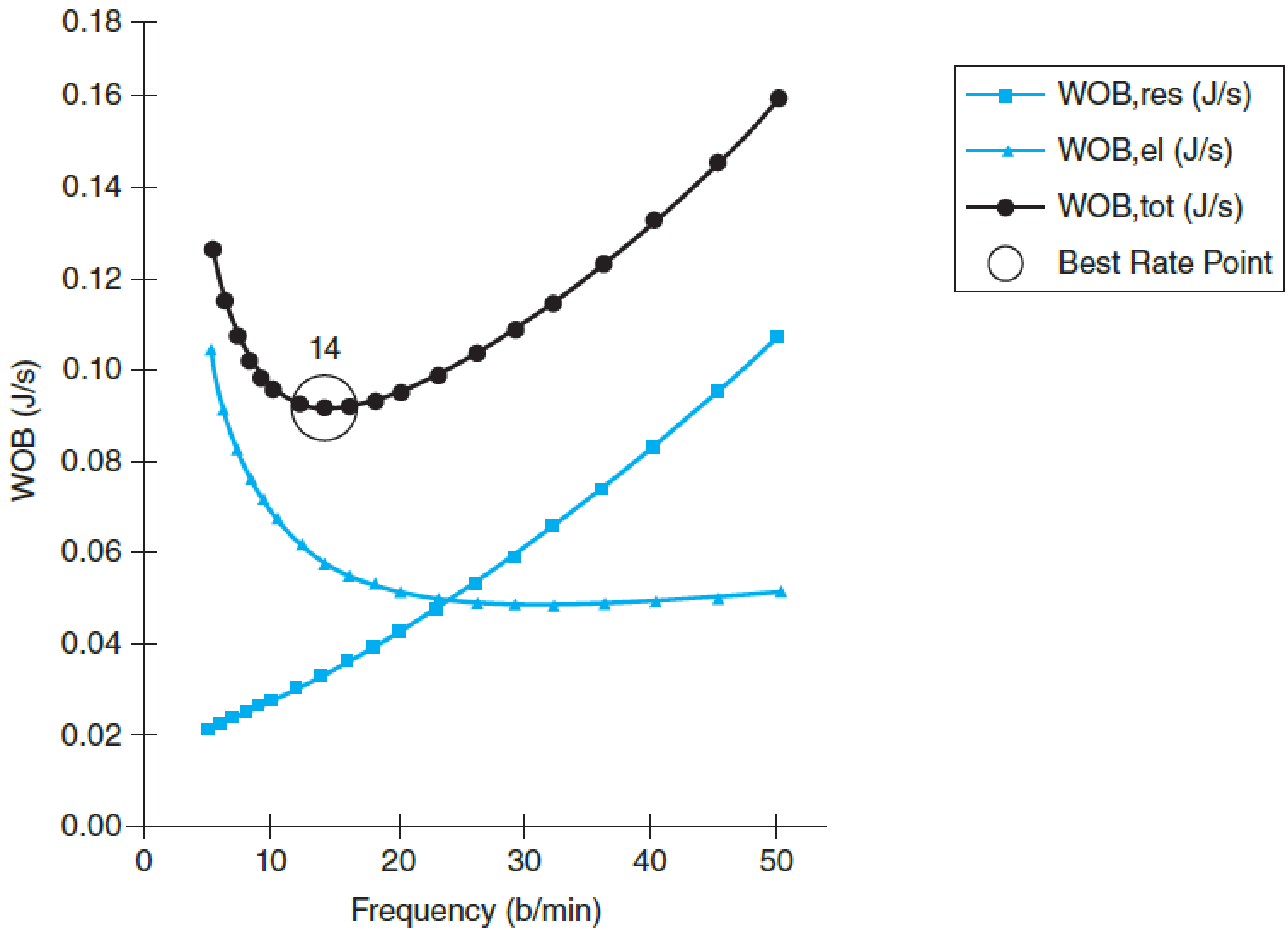
Otis Equation in ASV

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

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

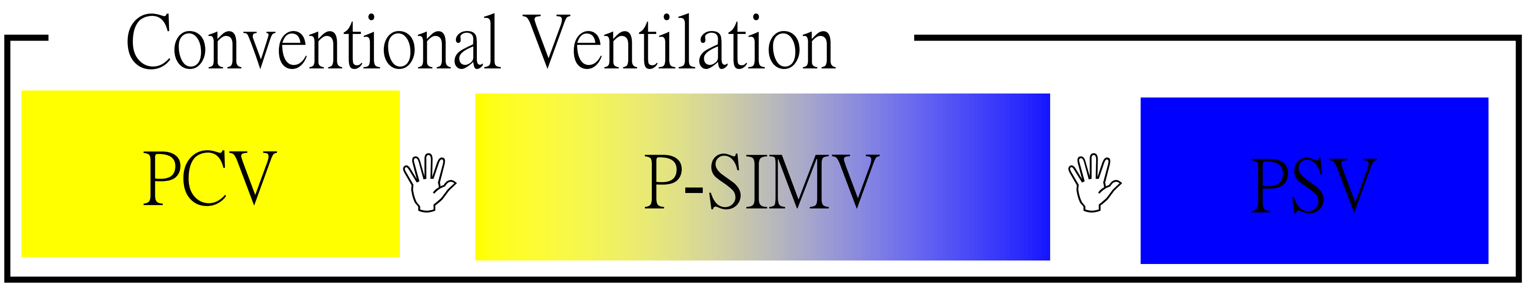
Adapted from Otis et al, JAP 2:592,1950

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

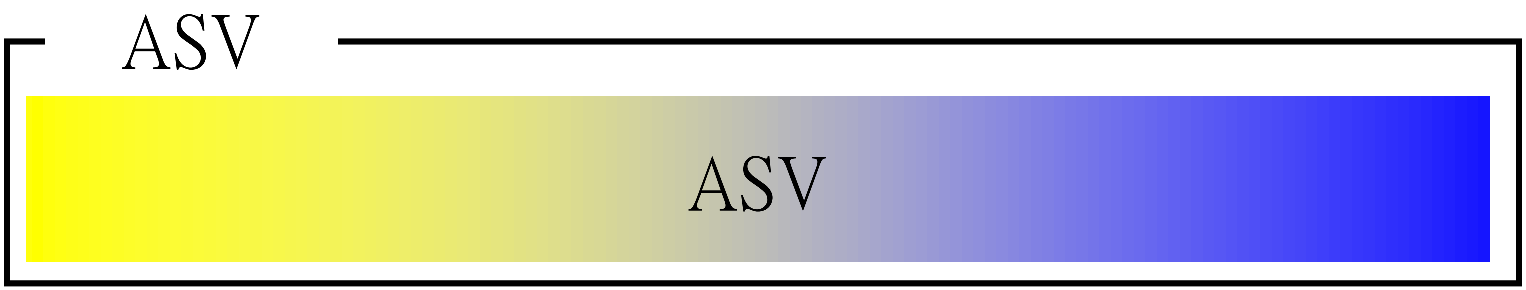


0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
WOB (J/s)
0
10
20
30
40
50
Frequency (b/min)
14
WOB,res (J/s)
WOB,el (J/s)
WOB,tot (J/s)
Best Rate Point

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

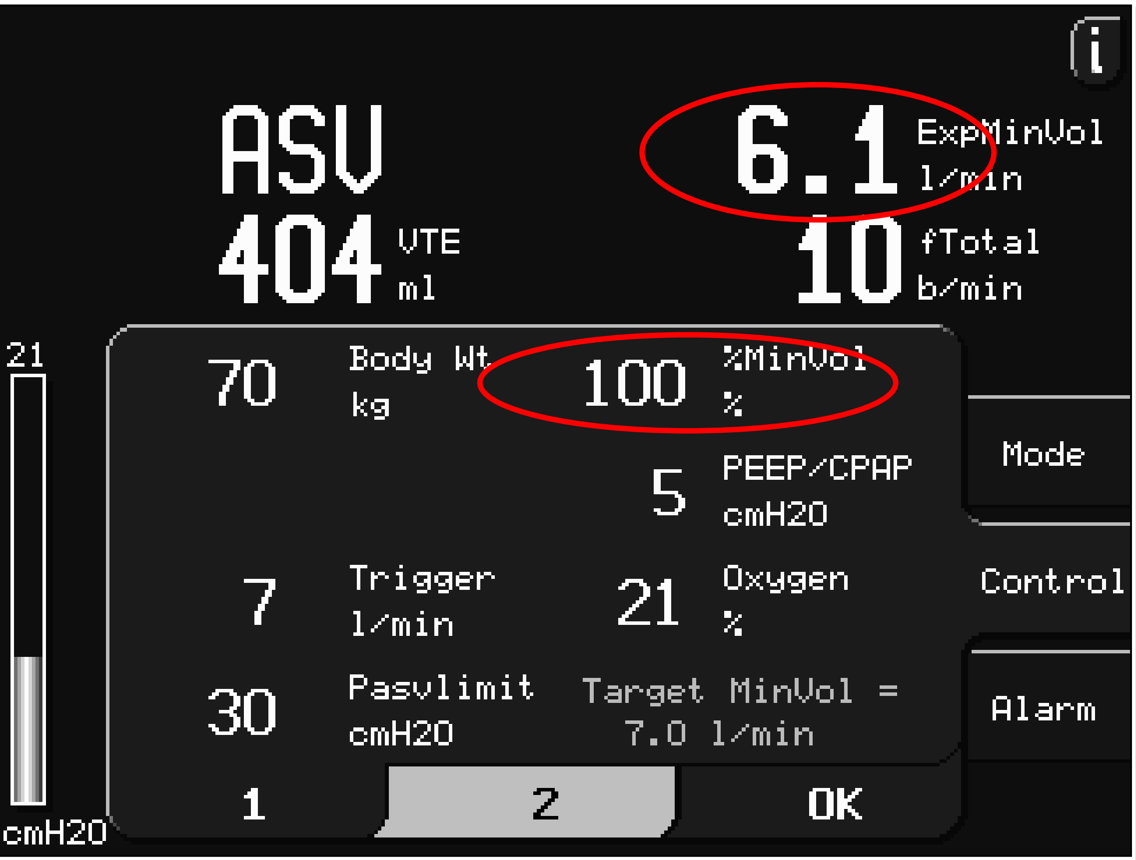


: Human intervention



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

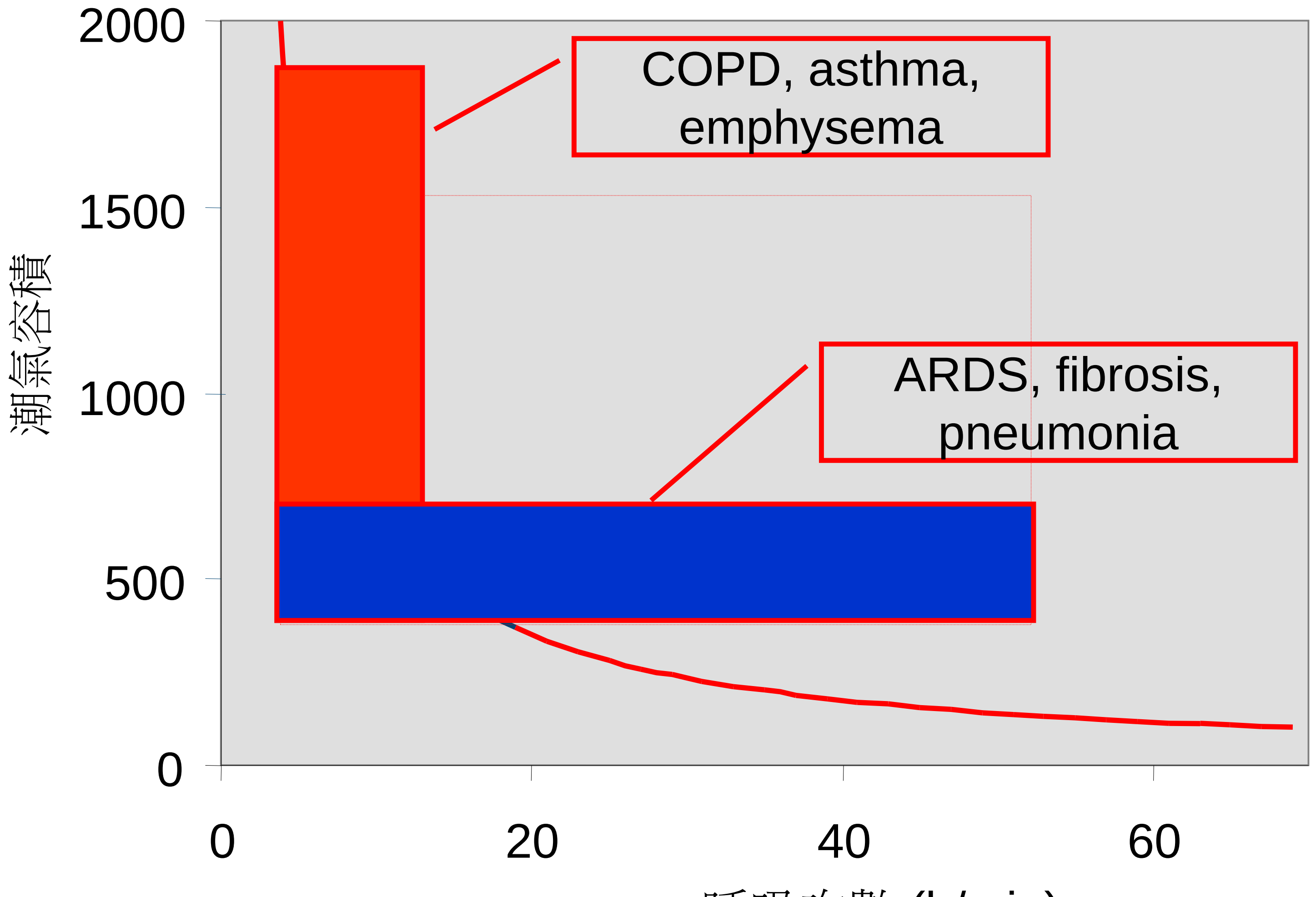
Adopted from Traub SL. Comparison of methods of estimating creatine clearance in children. Am J Hosp Pharm 1980;37:195-201

Adult

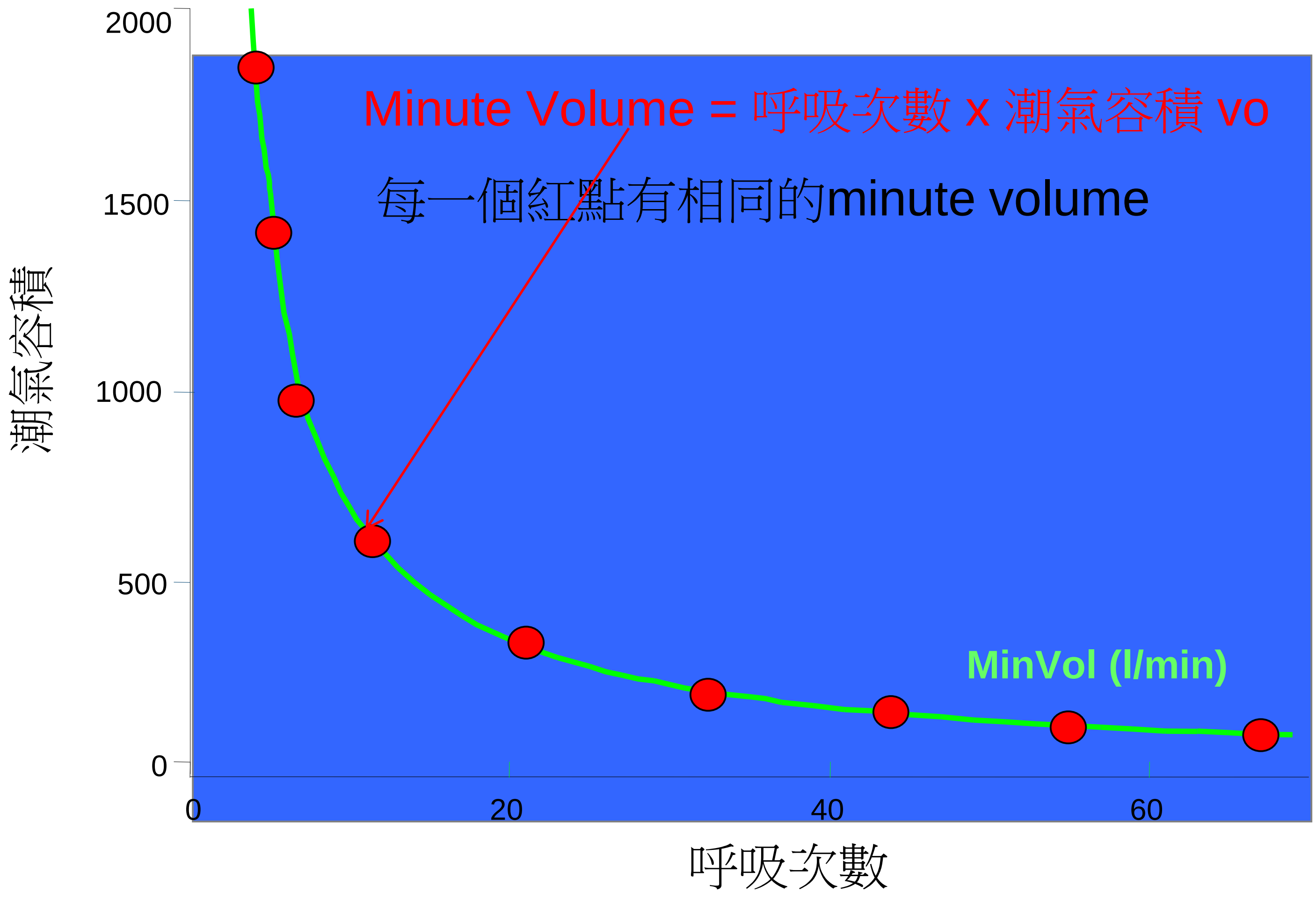
Height (ft)	Height (m)	IBW Male	IBW Female
5'0"	1.52	50	46
5'1"	1.55	52	48
5'2"	1.57	55	50
5'3"	1.60	57	52
5'4"	1.62	59	55
5'5"	1.65	62	57
5'6"	1.67	64	59
5'7"	1.70	66	62
5'8"	1.72	68	64
5'9"	1.75	71	66
5'10"	1.77	73	69
5'11"	1.80	75	71
6'0"	1.82	78	73
6'1"	1.85	80	75
6'2"	1.88	82	78
6'3"	1.90	85	80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

Safe frame and underlying lung diseases

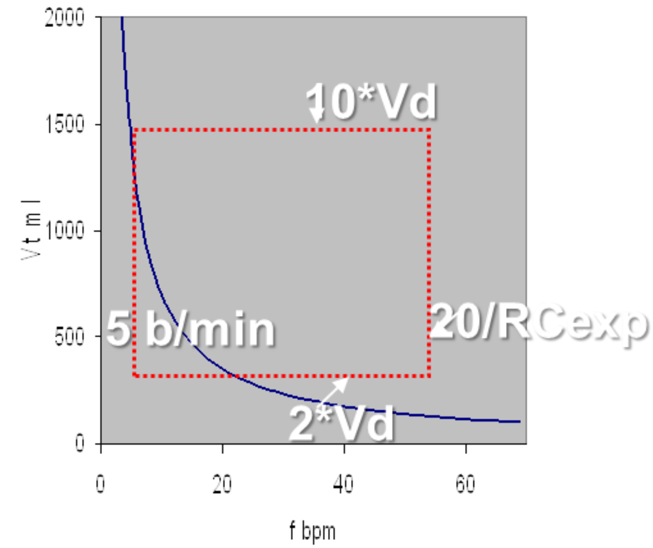


Step 4: 理想的呼吸次數,潮氣容積 (作功最小, 最舒服)



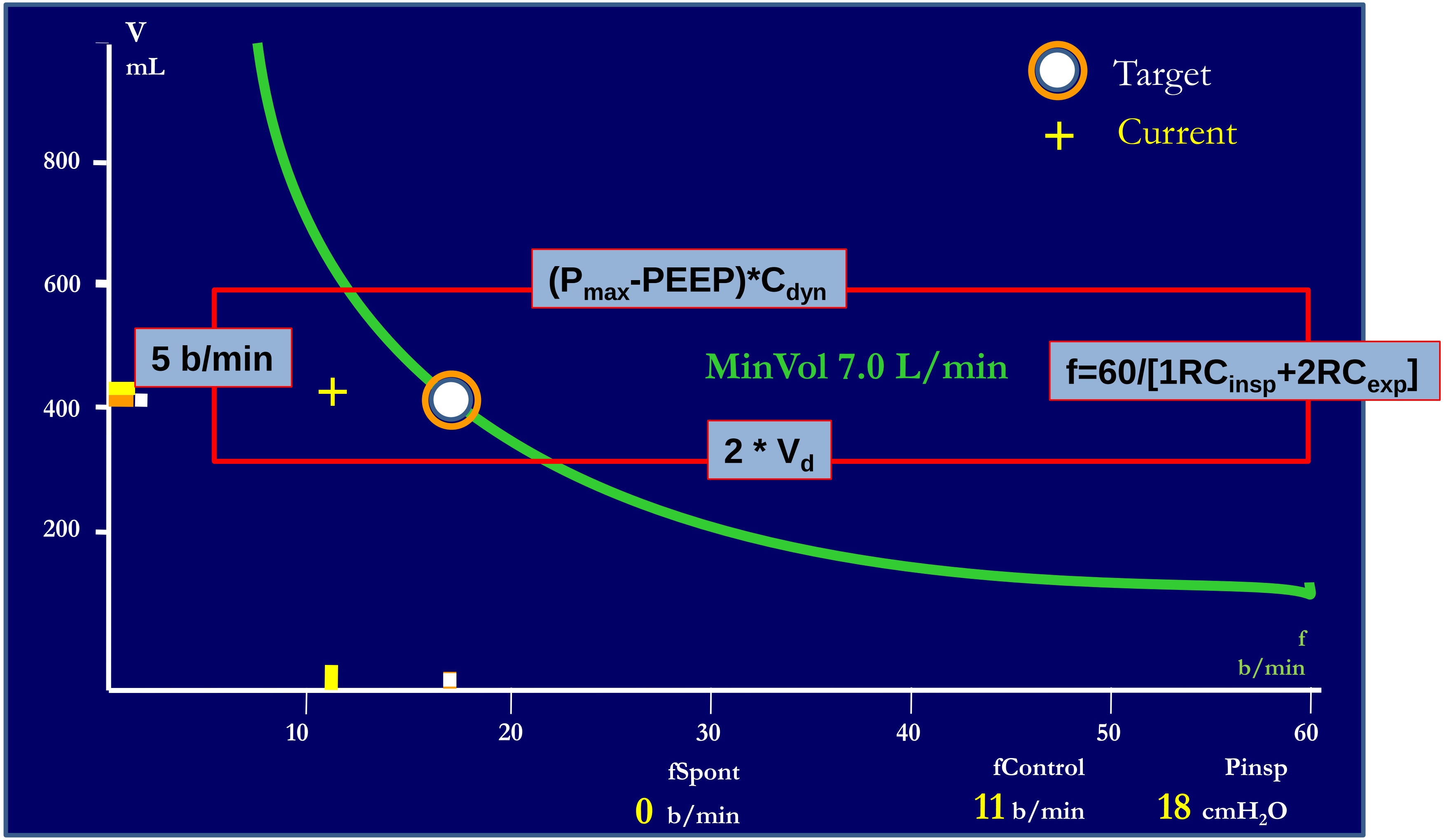
STEP 2_ ASV 3 test breath(得到病患資料 R, C, RCe)

STEP 3_ ASV 形成安全框框保護病人



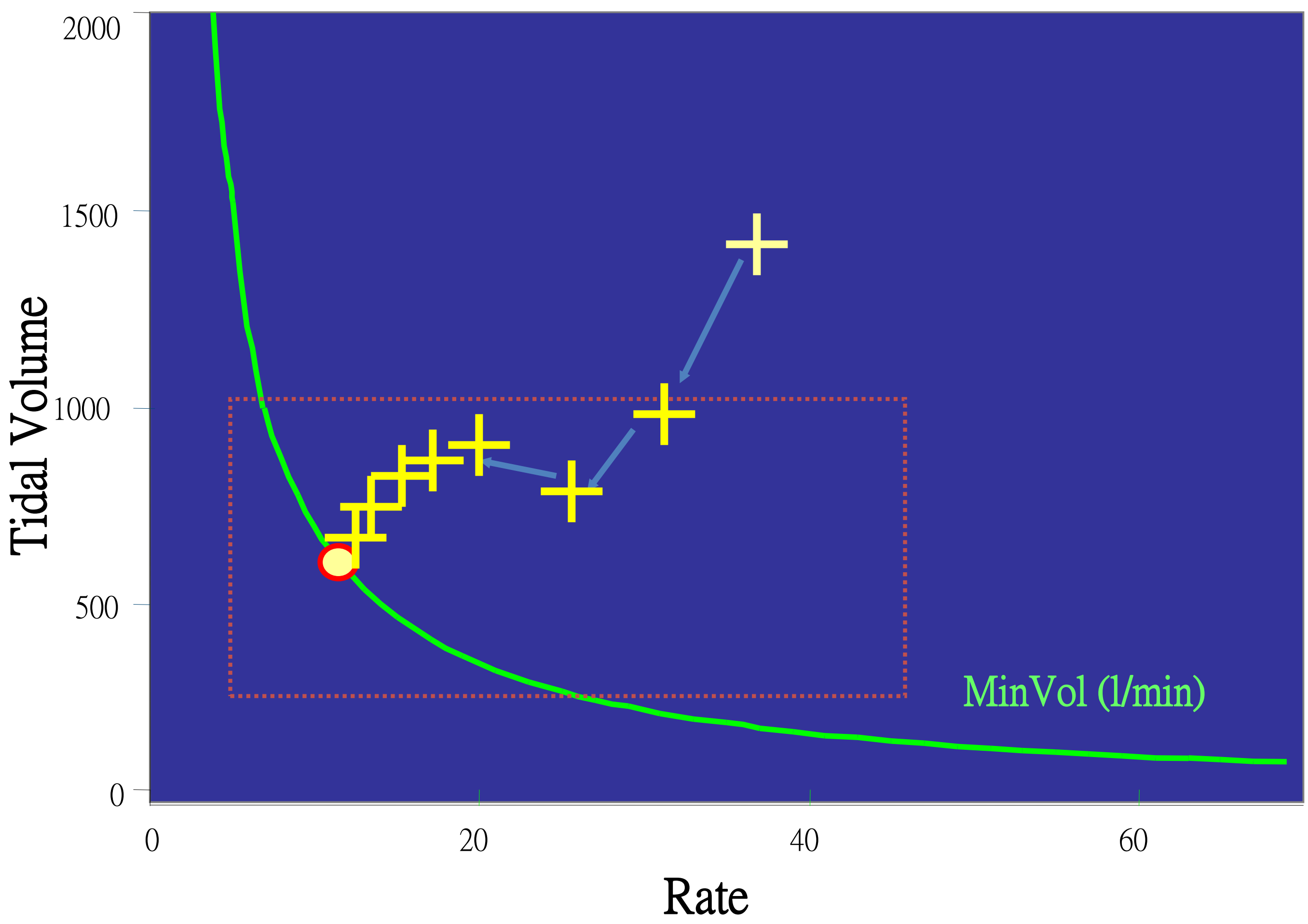
Parameters	Minimum Limit	Maximum Limit
Inspiratory pressure	PEEP + 5 cmH_2O	P_{high} + 10 cmH_2O
Tidal volume	4.4 ml/kg BodyWt ($2*V_{DS}$)	22 ml/kg BodyWt ($10*V_{DS}$)
Mandatory rate	5 /min	60 /min
Inspiratory time	RC_{Exp} or 0.5 sec	$2*RC_{Exp}$ or 3 sec
Expiratory time	2*RC Exp	12 sec

The Safety Window: low rate/volume limits



Step 5_ A S V自動調整:Pinsp & fSIMV趨近理想值

Step 6_ User 評估增減 % (MV)



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
18 Ppeak cmH2O
18 Pplateau cmH2O
11 Pmean cmH2O
5 PEEP/CPAP cmH2O
5.0 Pminimum cmH2O
1 / 6
Paw cmH2O
Flow L/min
s
Rinsp 9 cmH2O/l/s
Cstat 24 ml/cmH2O
170 cm, Male
V ml
Target
Current
MinVol 6.6 l/min
f b/min
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
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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 Vm to meet patient demand
- Decelerating flow waveform for improved gas distribution
- Breath by breath analysis

Ventilator Setting in Clinical Practice

Disease	Condition
ARDS	Low tidal volume, high PEEP, lower transpulmonary pressure
Brain edema	PaCO2 28-32 mmHg, careful use of PEEP
Restrictive lung disease (intrapulmonary)	Vt 7-10 ml/kg, higher rate
Restrictive lung disease (extrapulmonary)	Vt 12-15ml/kg (adequate Ptp)
Cardiogenic pulmonary edema	Moderate PEEP (8-10cmH2O)

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