Mechanical Ventilation
Waveforms and Modes
ISRC 43rd Annual Conference

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PULMONARY AND CRITICAL CARE

Common Initial Ventilator Settings
(Volume Controlled)

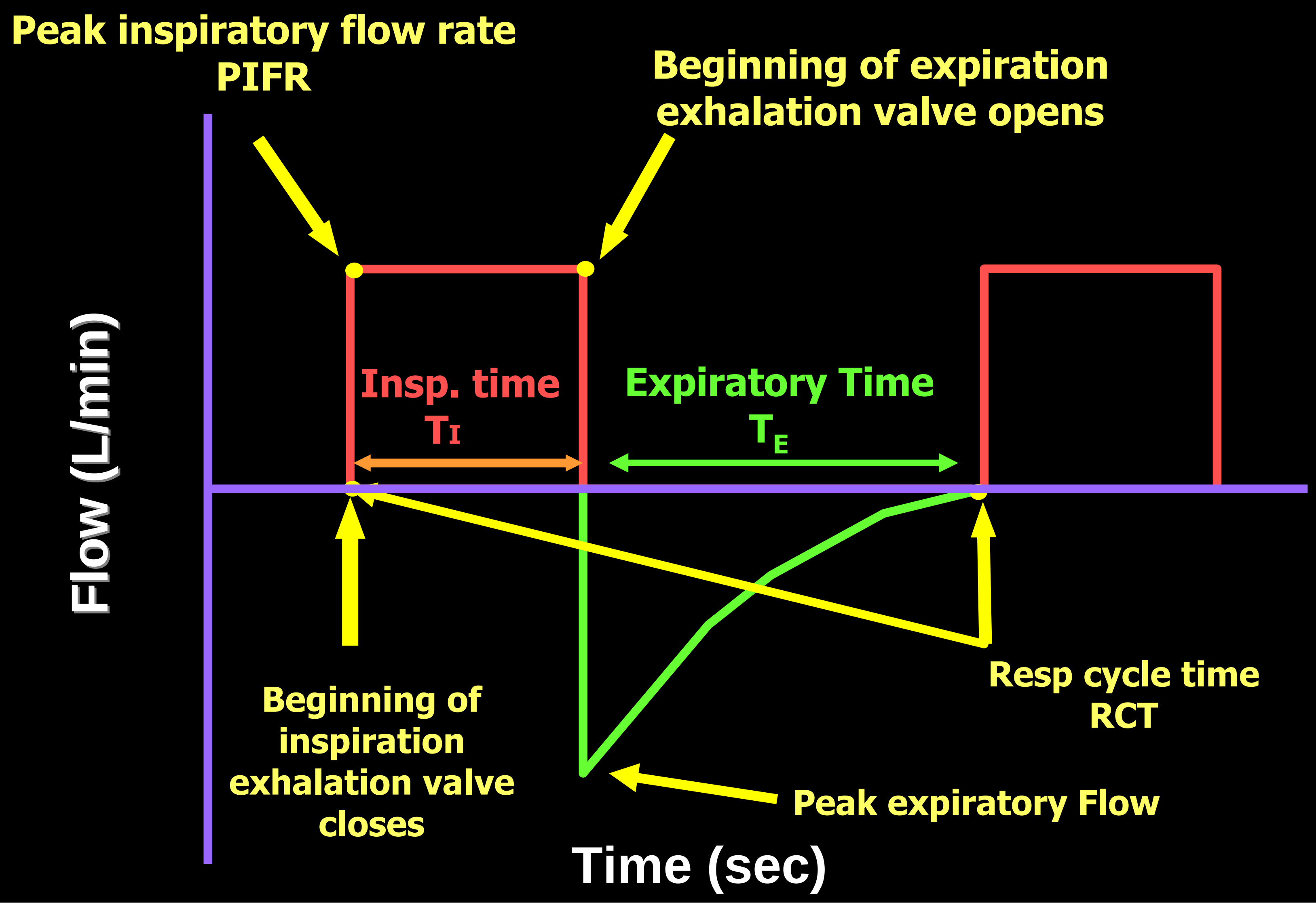
Mode	AC or SIMV	
RR	12 - 14/min	$PaCO_2$
V_T	7 - 8 ml/kg	
FiO_2	1.0	PaO_2
PEEP	5 cmH_2O	
Vi	60 L/m cont 80 L/m decel	

ABGs, airway pressures and patient-ventilator synchrony guide subsequent changes.

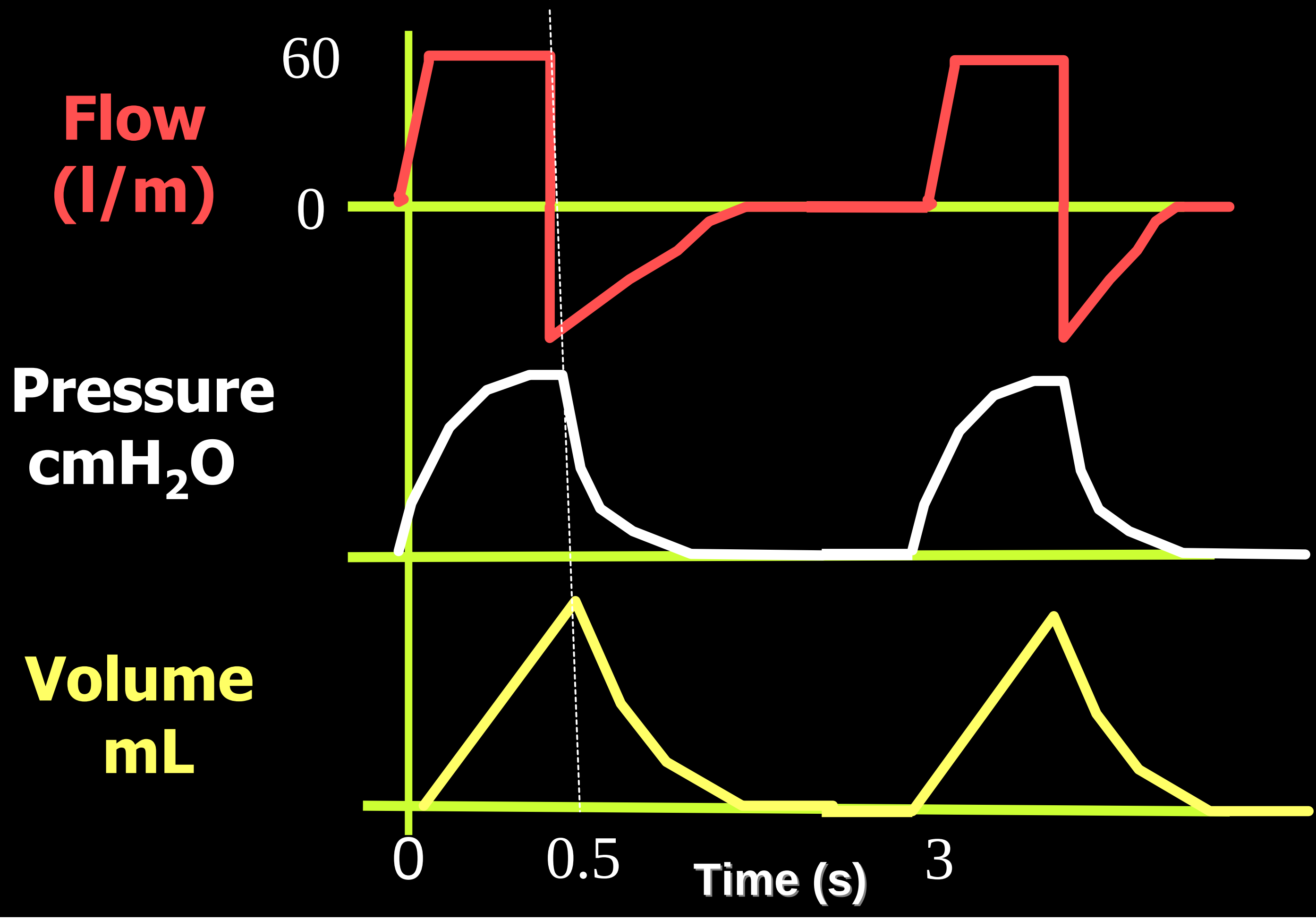
Singer B, Corbridge T. Basic Invasive Mechanical Ventilation. South Med J 2009: 102; 1238

The Mechanical Breath

Constant Inspiratory Flow



Flow-Pressure-Volume Relationships



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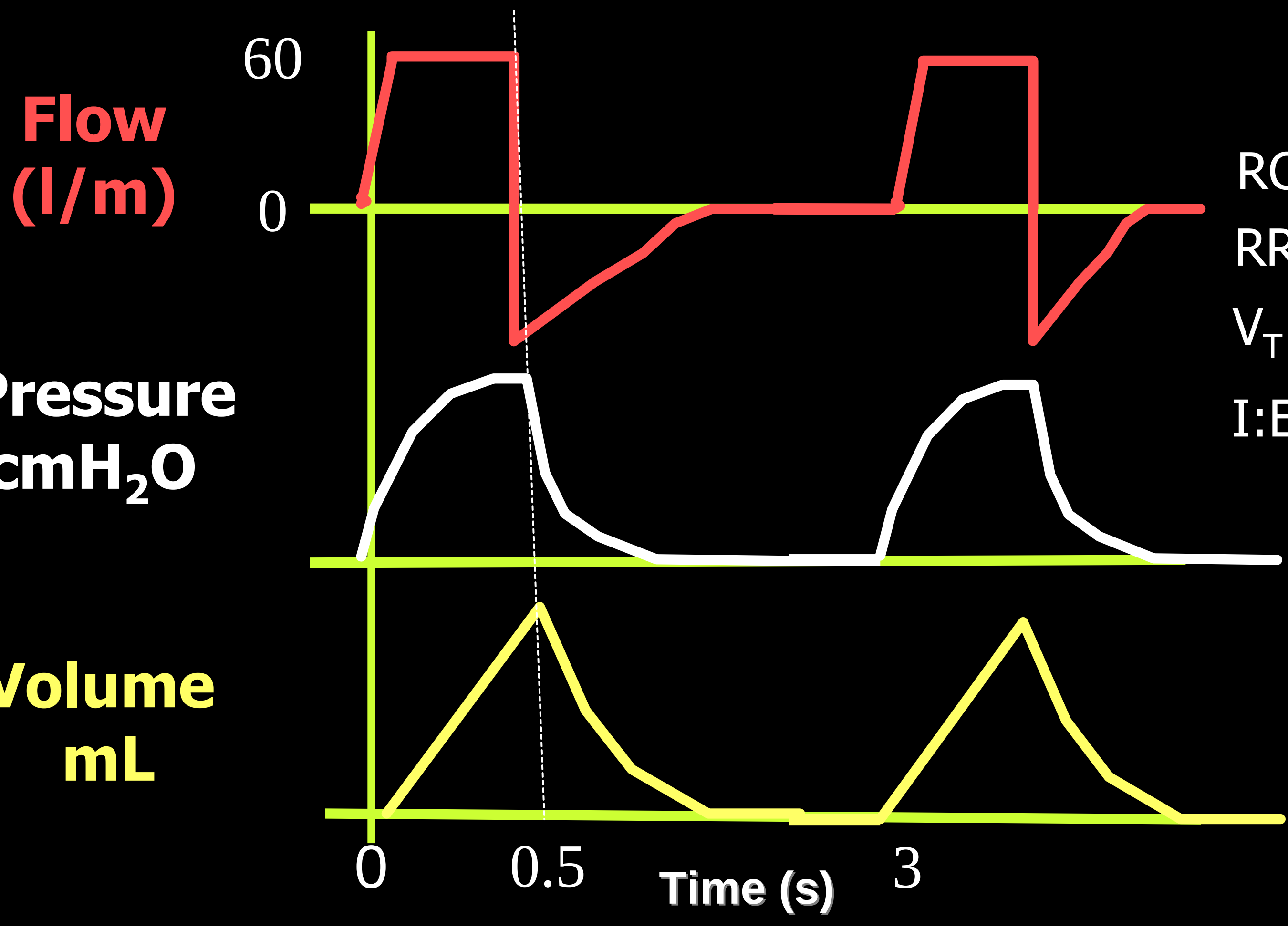


RCT = 3 s

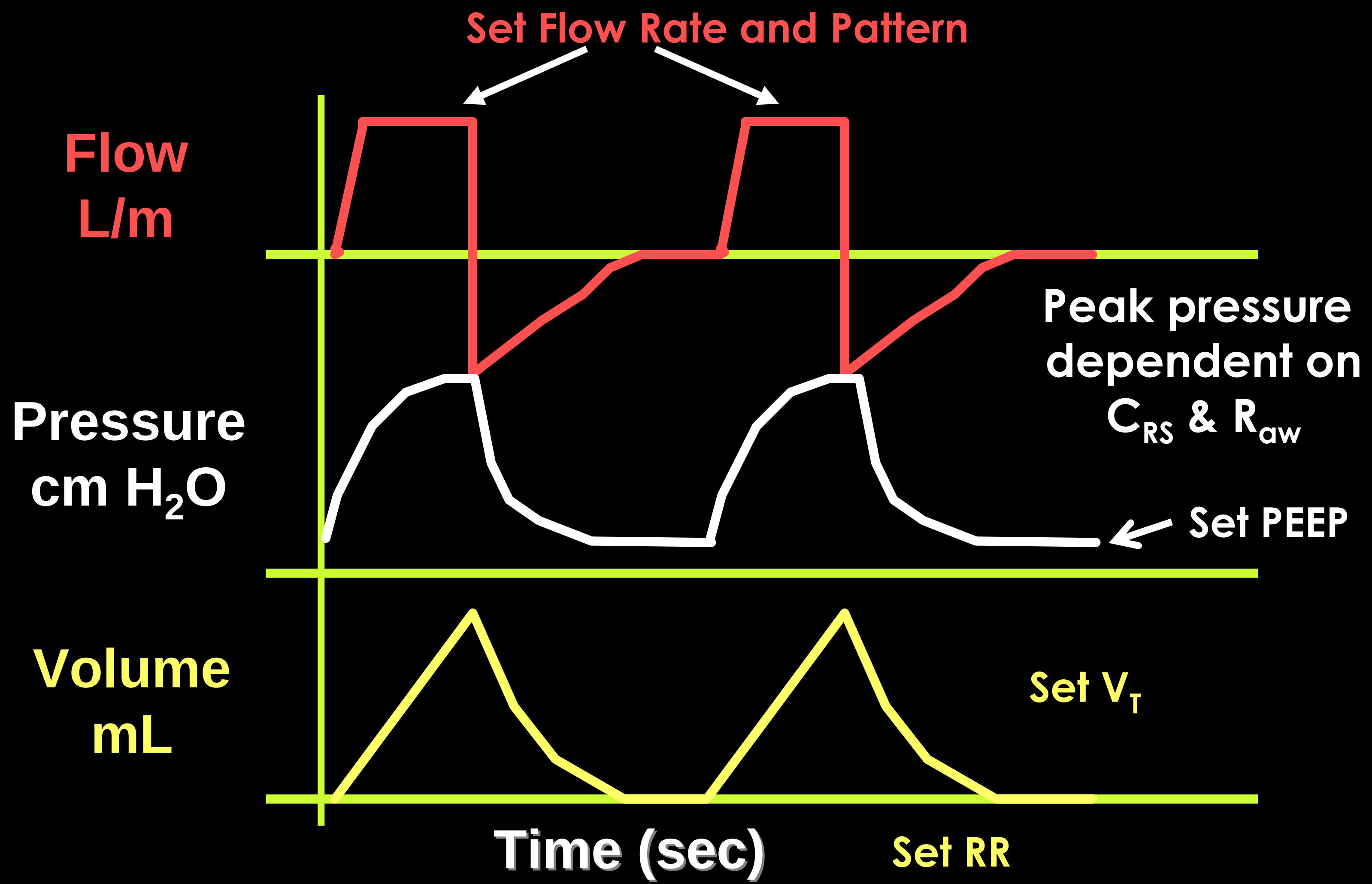
RR = 20/min

V_T = 500 ml

I:E = 1:5

Controlled Mode
(Volume Controlled)

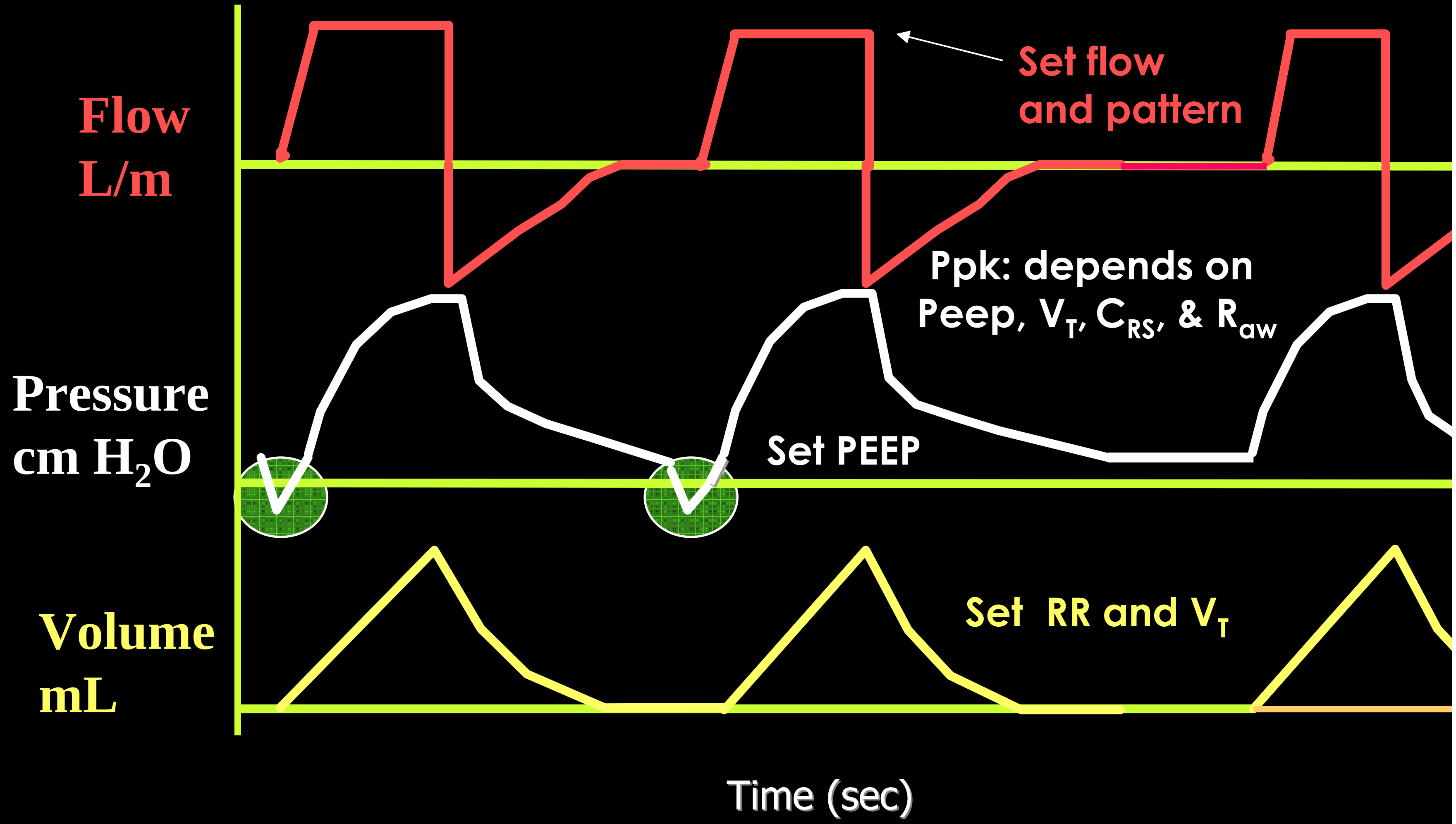
Time triggered, Flow limited, Volume cycled



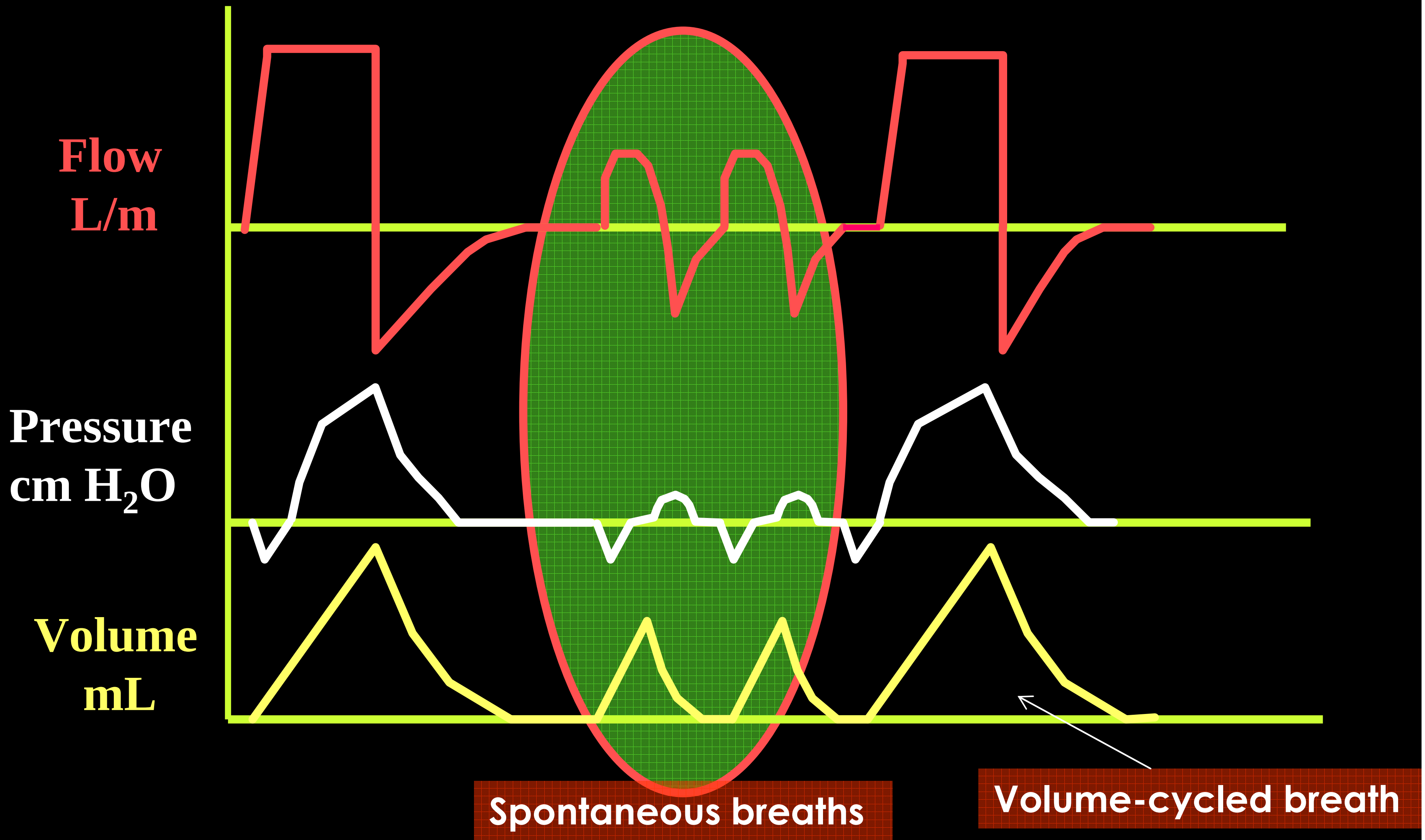
Assist Control

(AC, Volume Controlled)

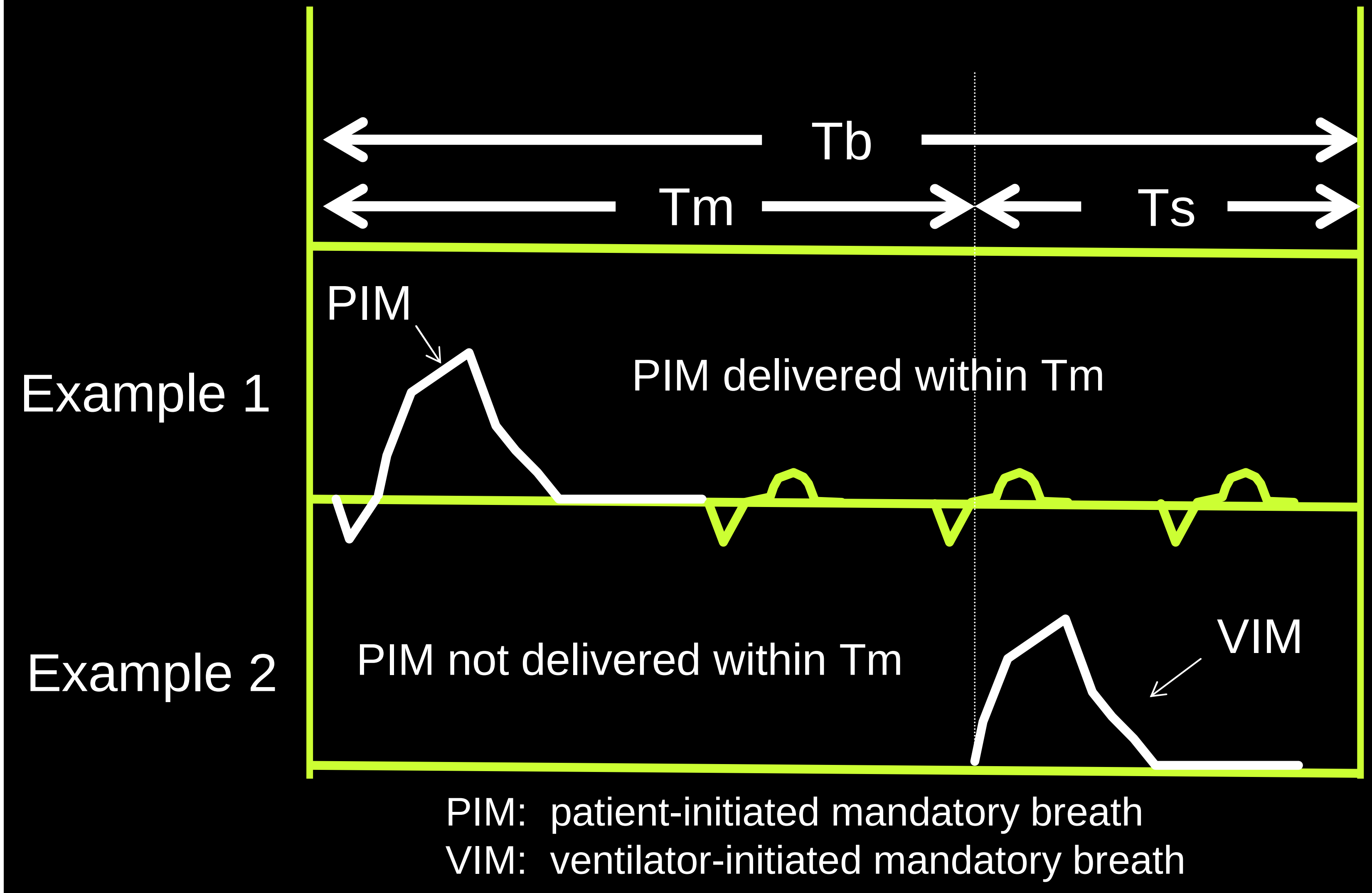
Patient/time triggered, Flow limited, Volume cycled



Synchronized Intermittent Mandatory Ventilation: a Mixed Mode
(SIMV, Volume Controlled)

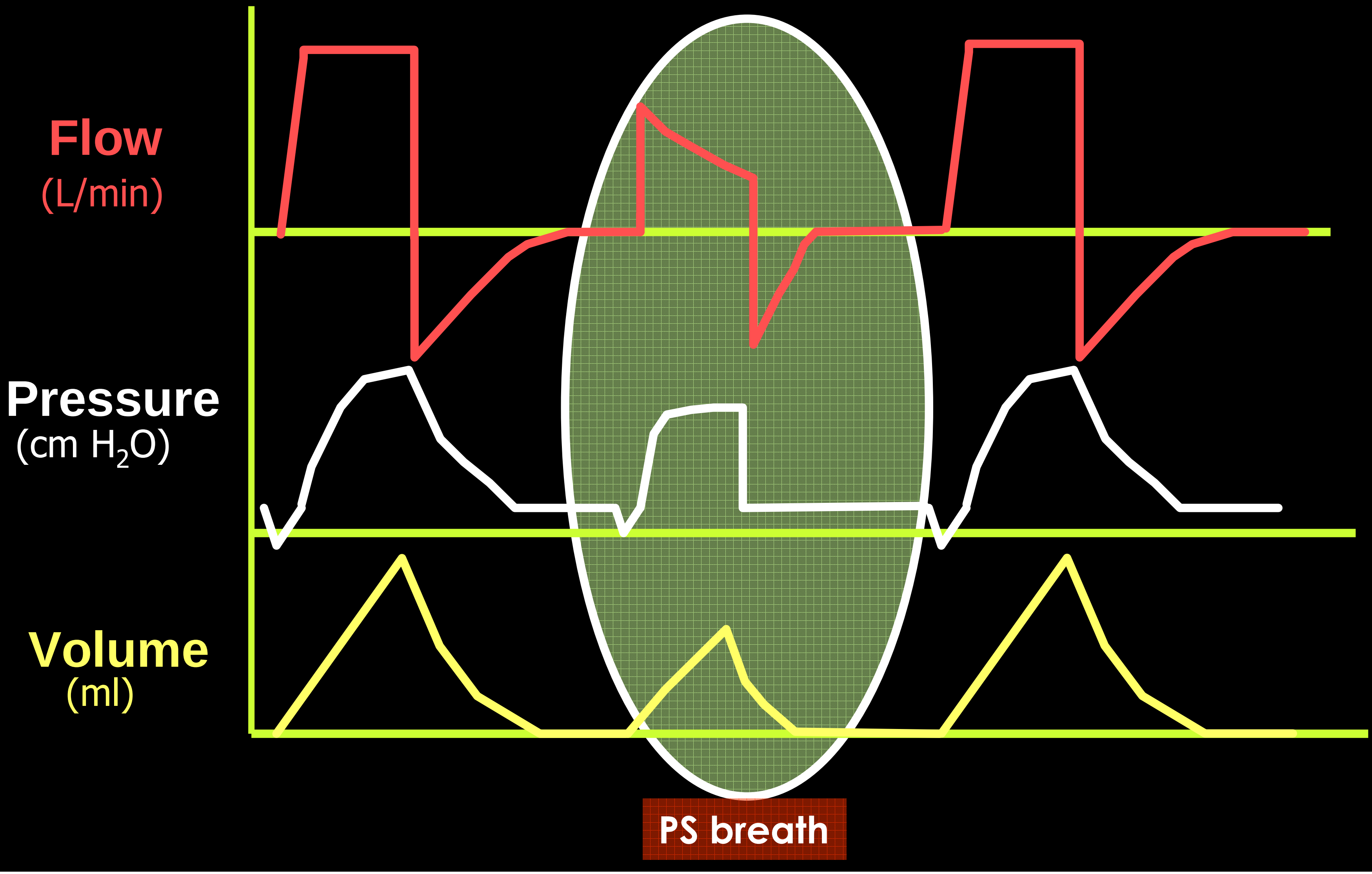


Synchronized Intermittent Mandatory Ventilation (SIMV)

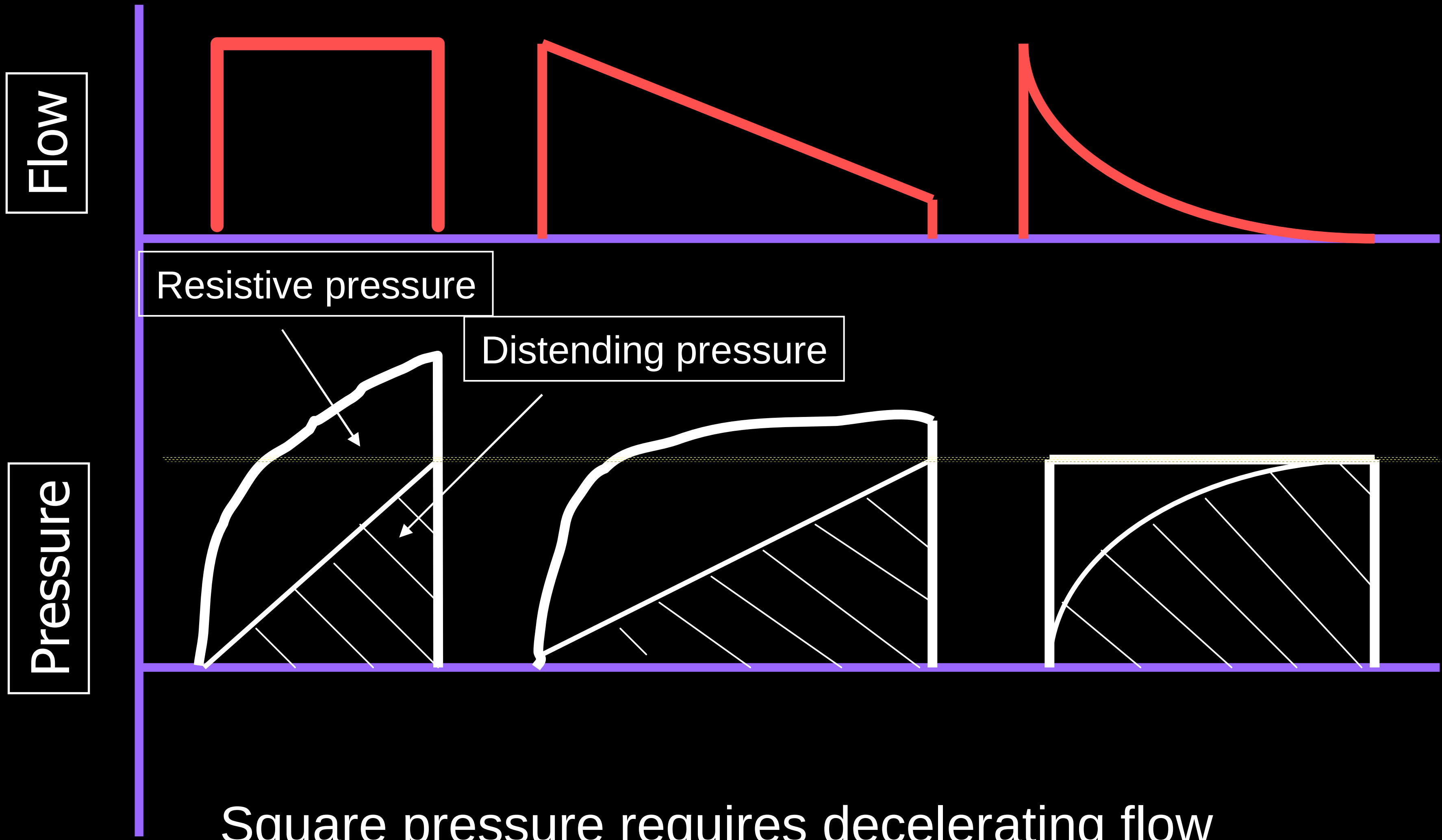


SIMV+PSV

(Mixed Mode)



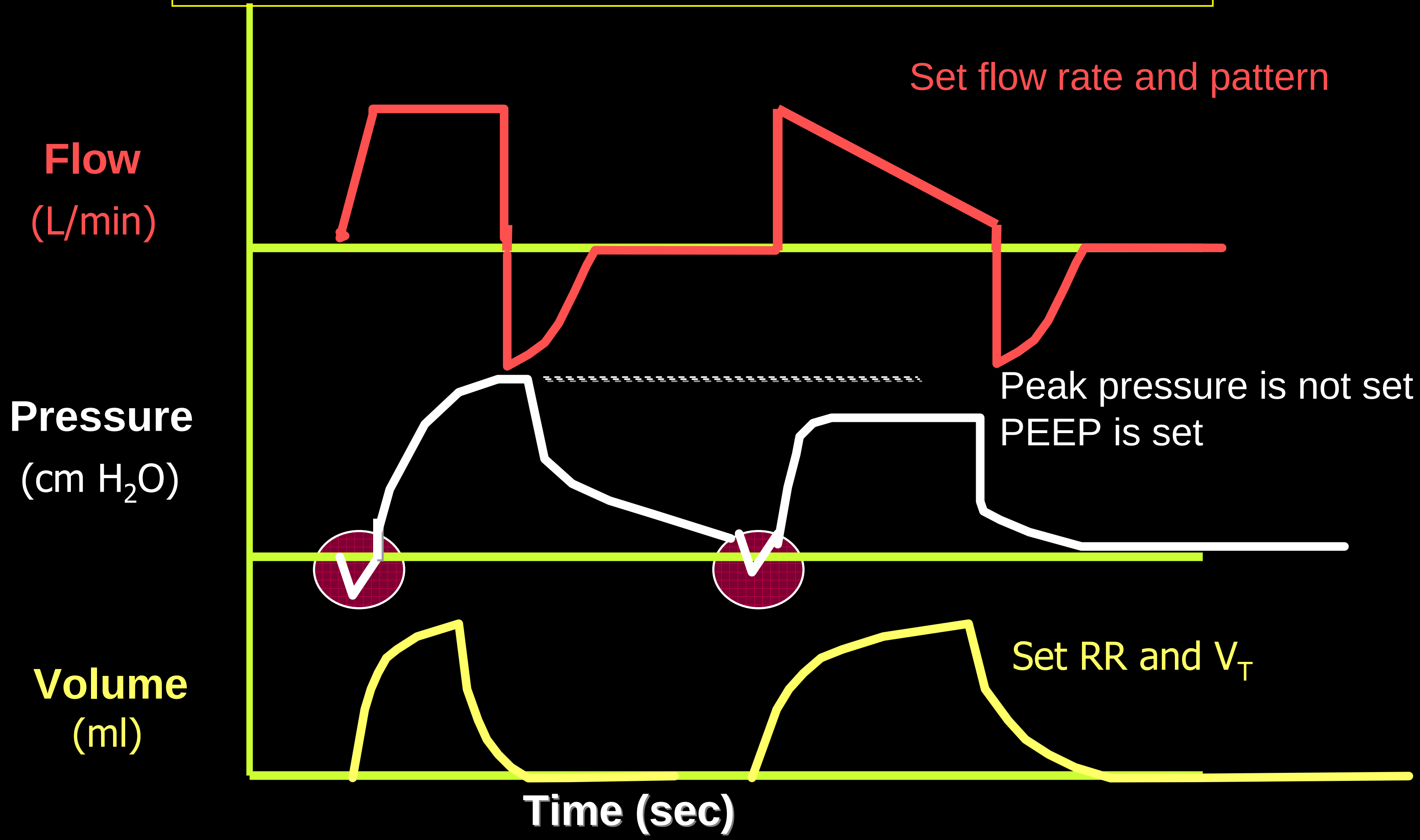
Flow-Pressure Relationships



Square pressure requires decelerating flow

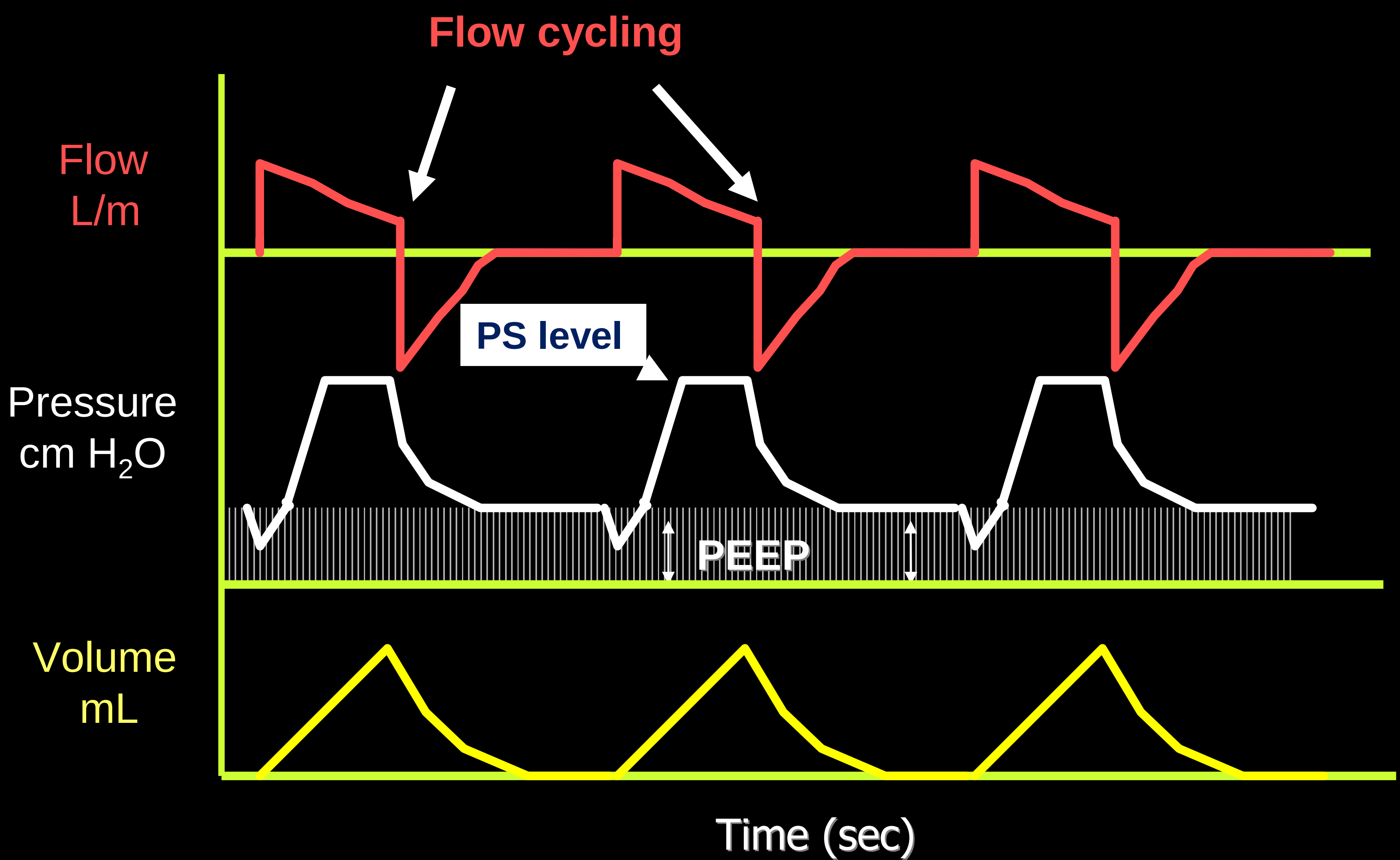
Constant vs Decelerating Flow (AC, Volume Controlled)

Time/Pt triggered, Flow limited, Volume cycled



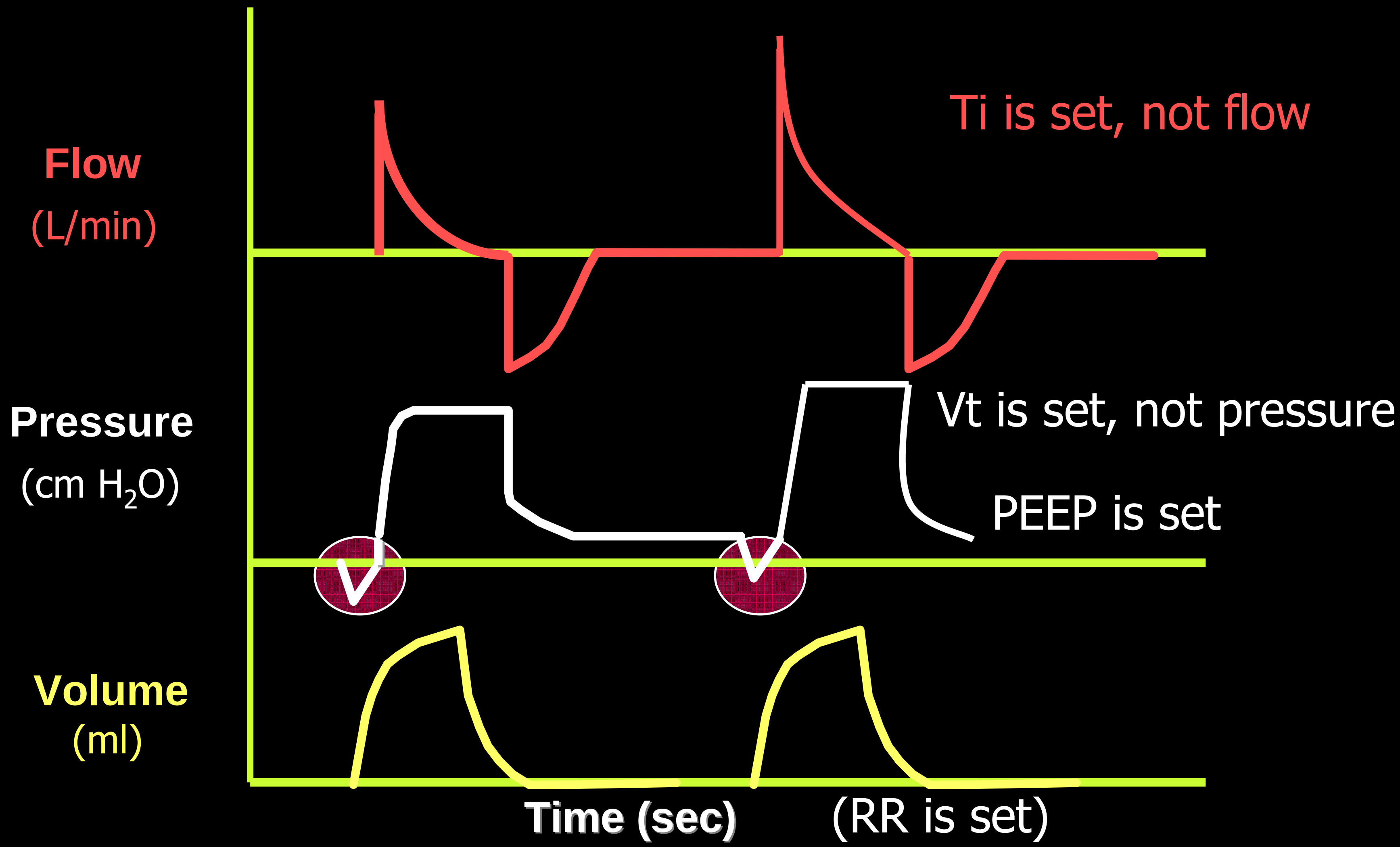
Pressure Support Ventilation (PSV)

Patient triggered, Pressure limited, Flow cycled

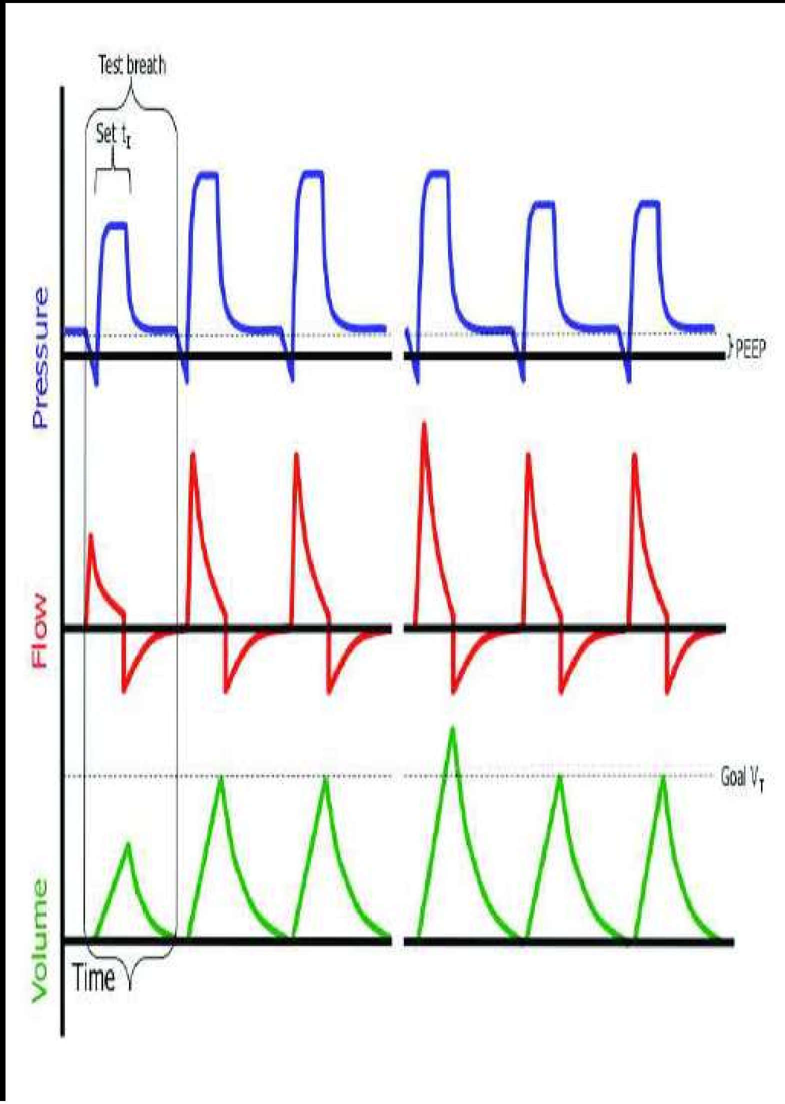


Pressure Regulated Volume Controlled Ventilation (VC Plus)

(AC, Volume Controlled)

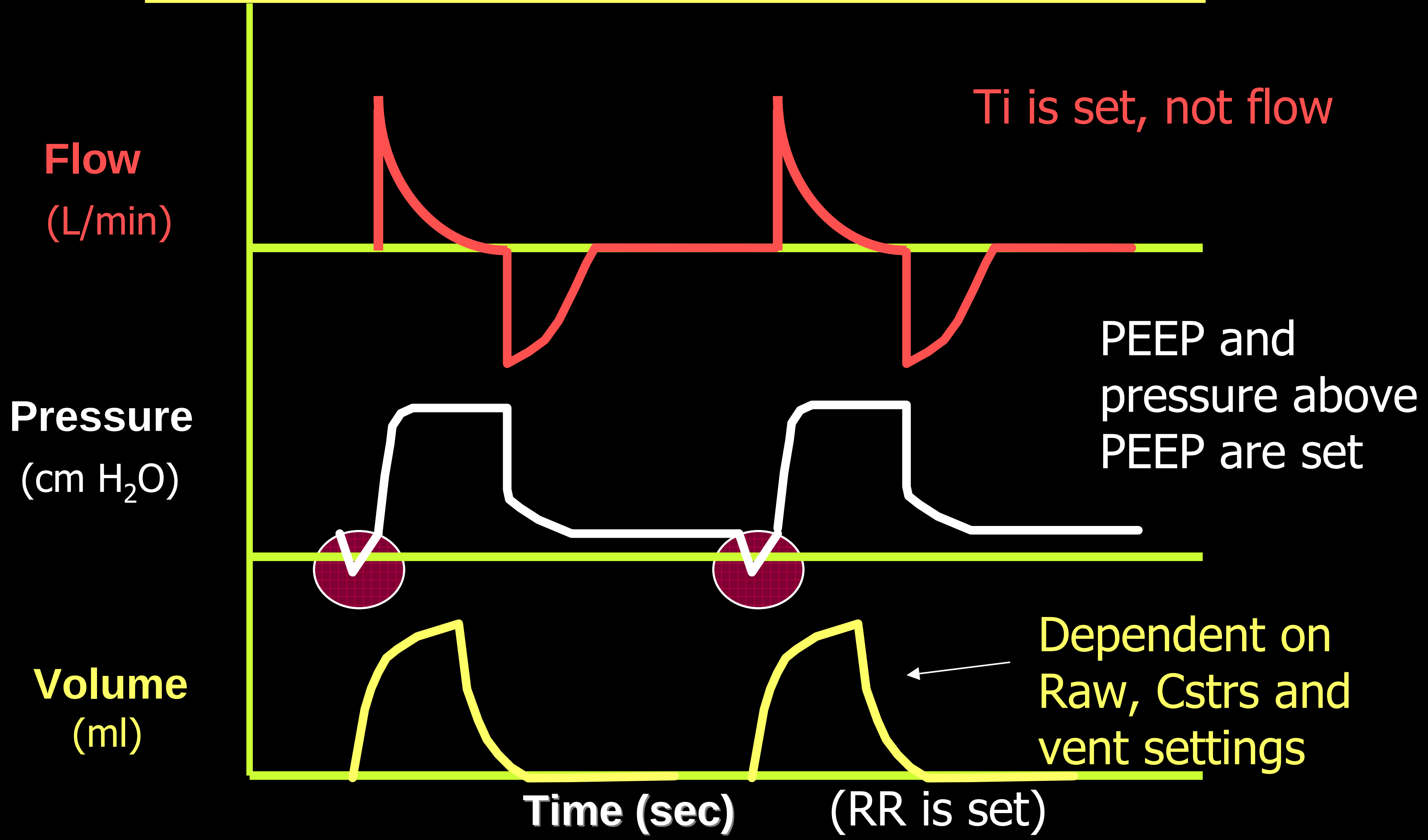


Pressure Regulated Volume Controlled Ventilation (VC Plus)



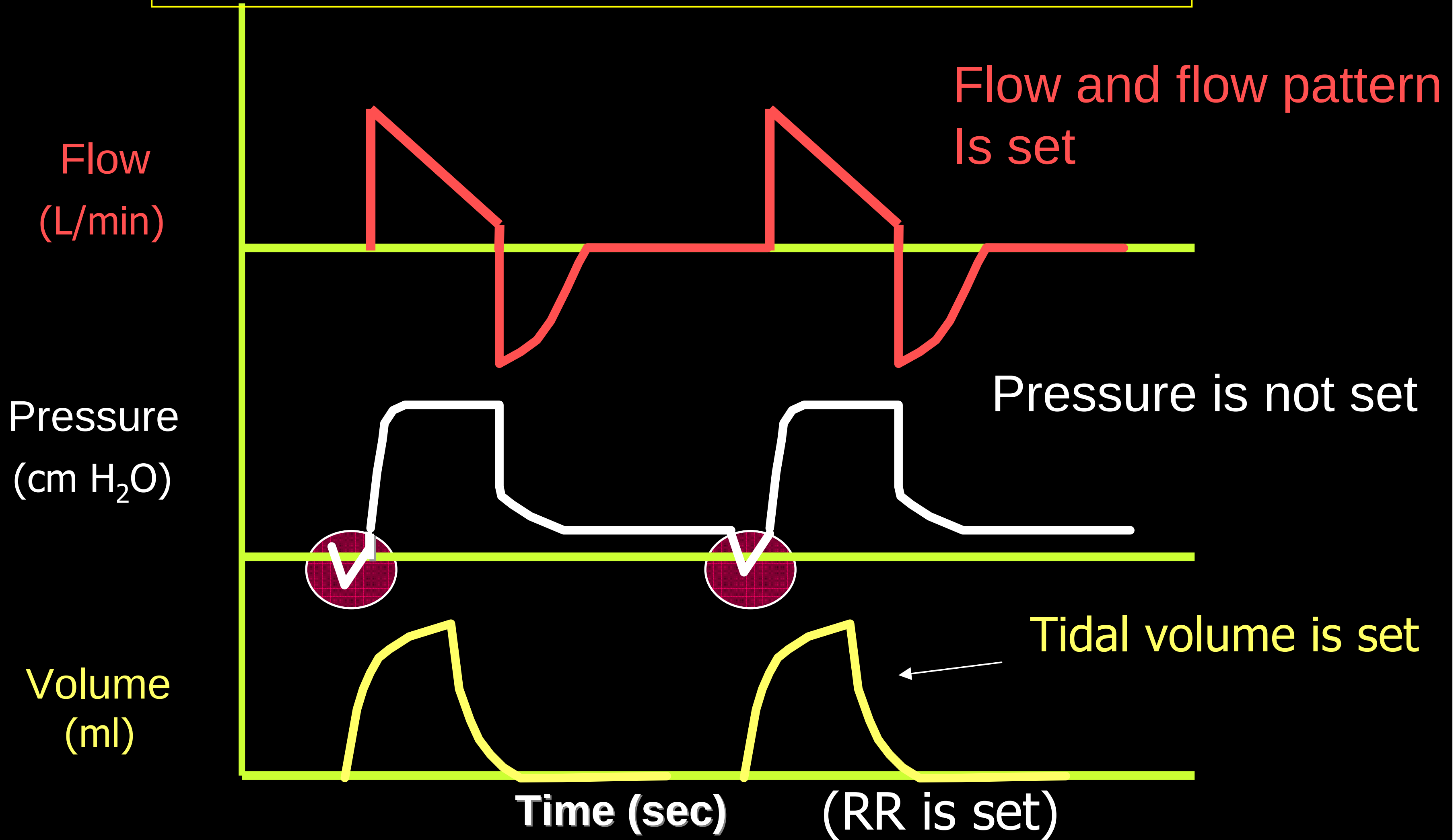
Pressure-Controlled Ventilation
(AC, Pressure Controlled)

Time/pt triggered, Pressure limited, Time cycled



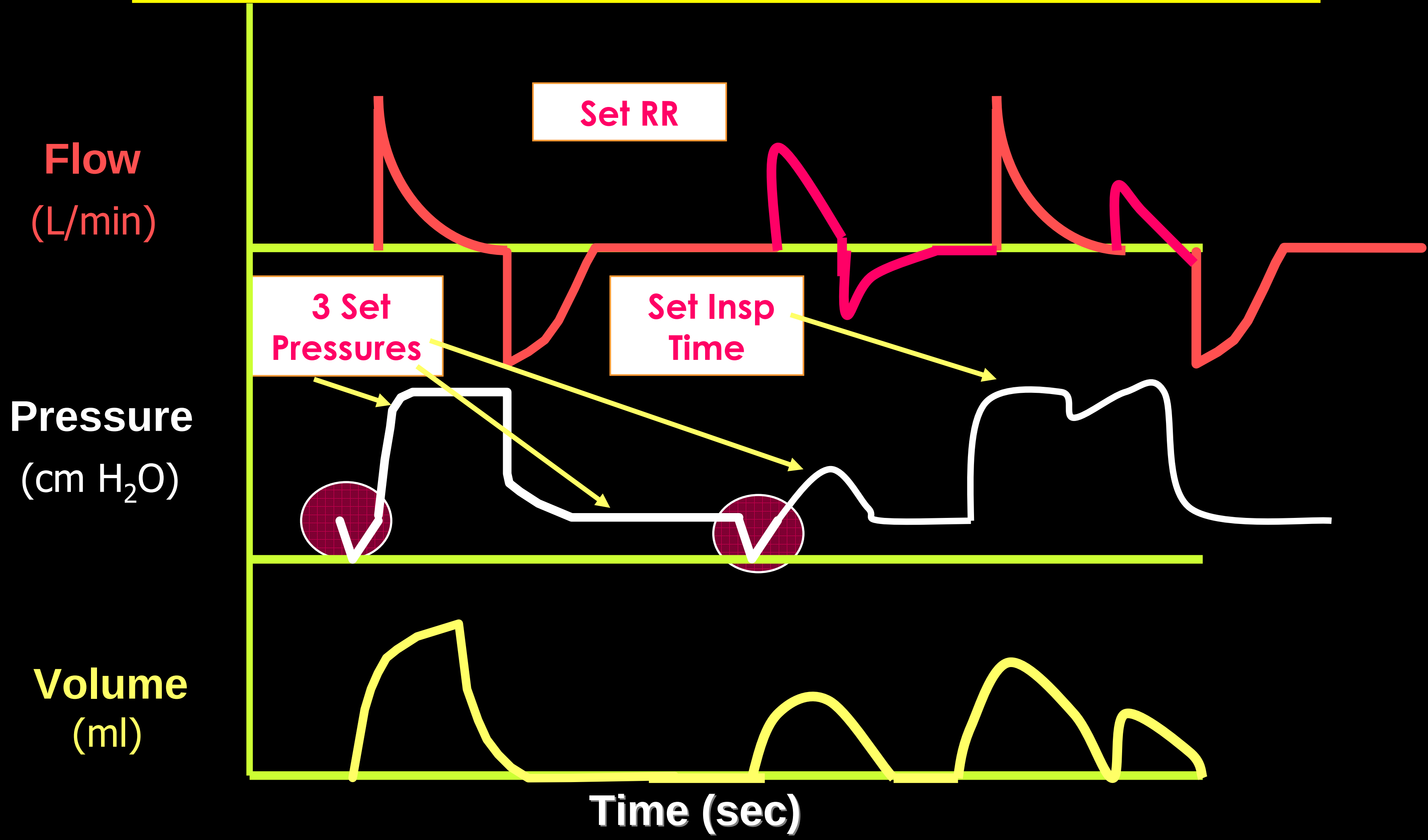
Volume-Controlled Ventilation
(AC, Volume Controlled/Decelerating flow)

Time/Pt triggered, Flow limited, Volume cycled



Biphasic (Bilevel)
(Pressure Controlled Ventilation)

Time/Pt Triggered, Pressure Limited, Flow/Time Cycled



Biphasic (Bilevel)

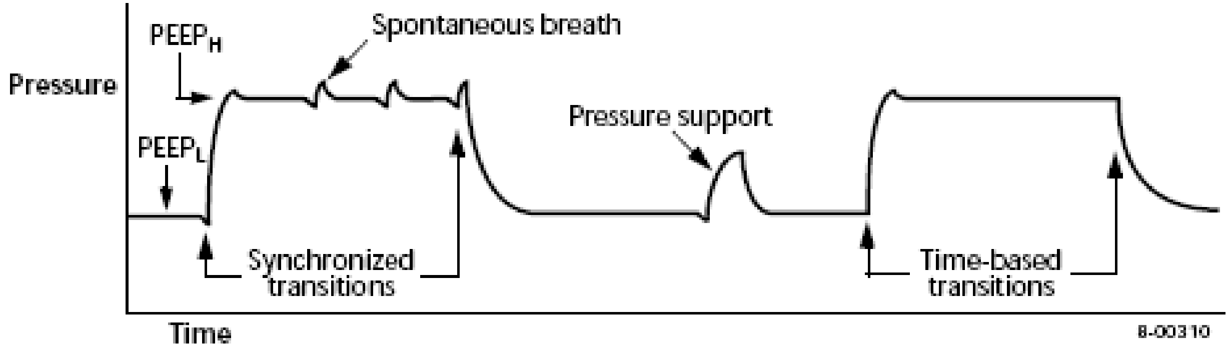


Figure 1. *BiLevel* mode

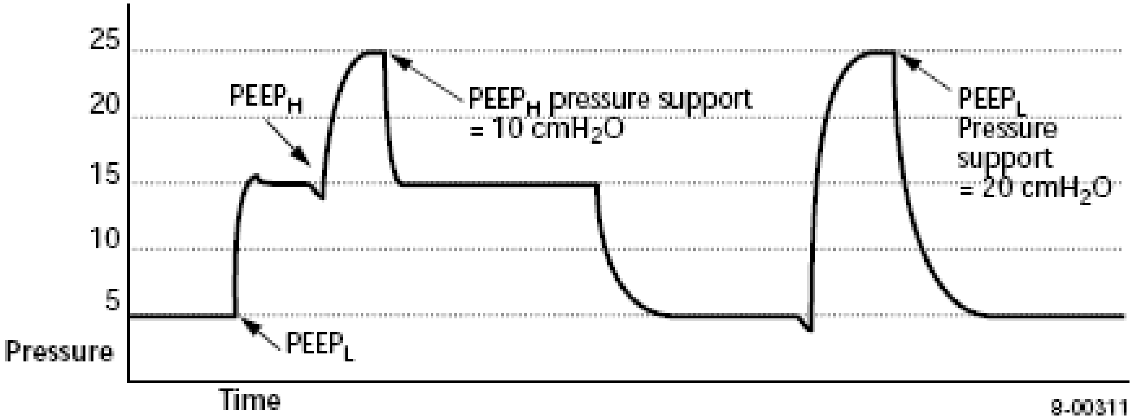
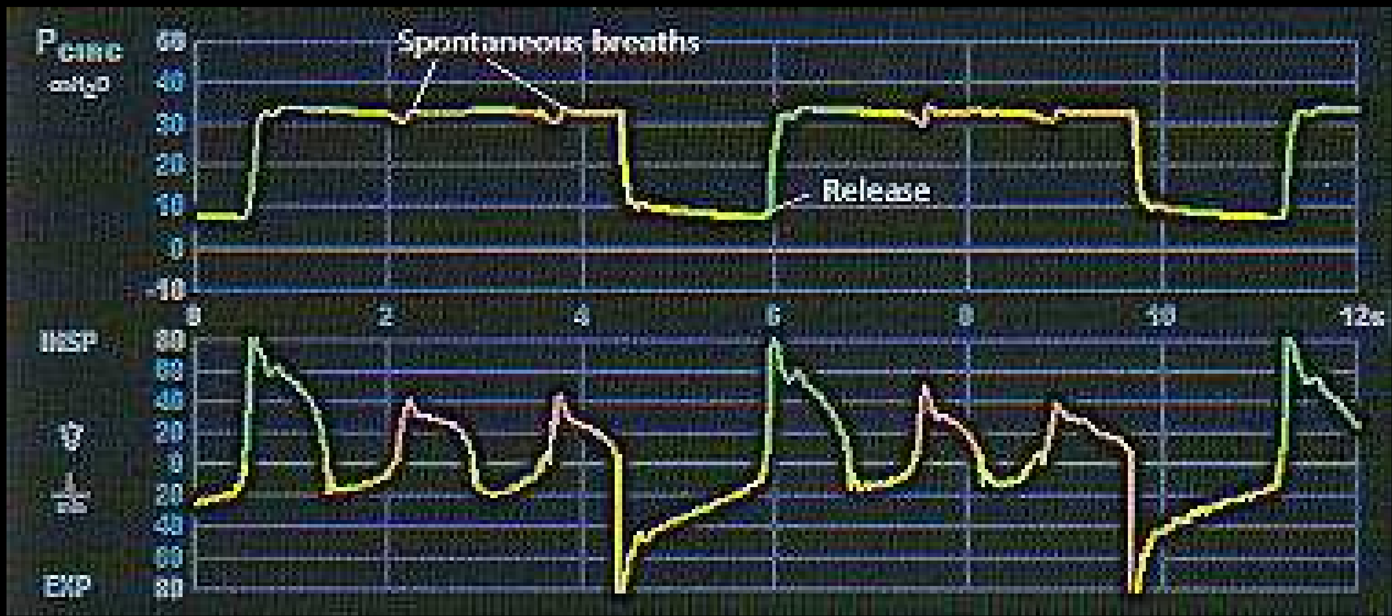
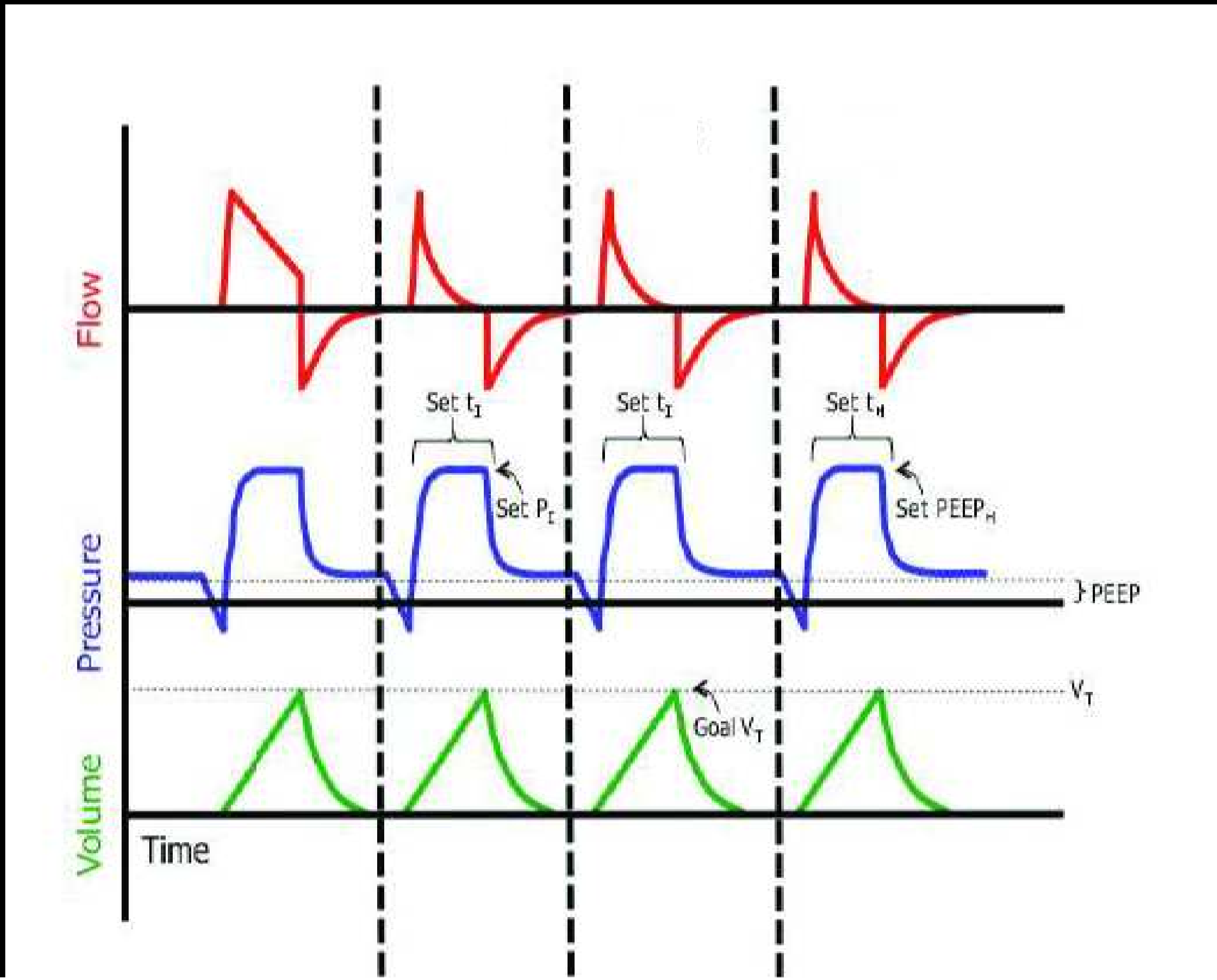


Figure 2. *BiLevel* with pressure support

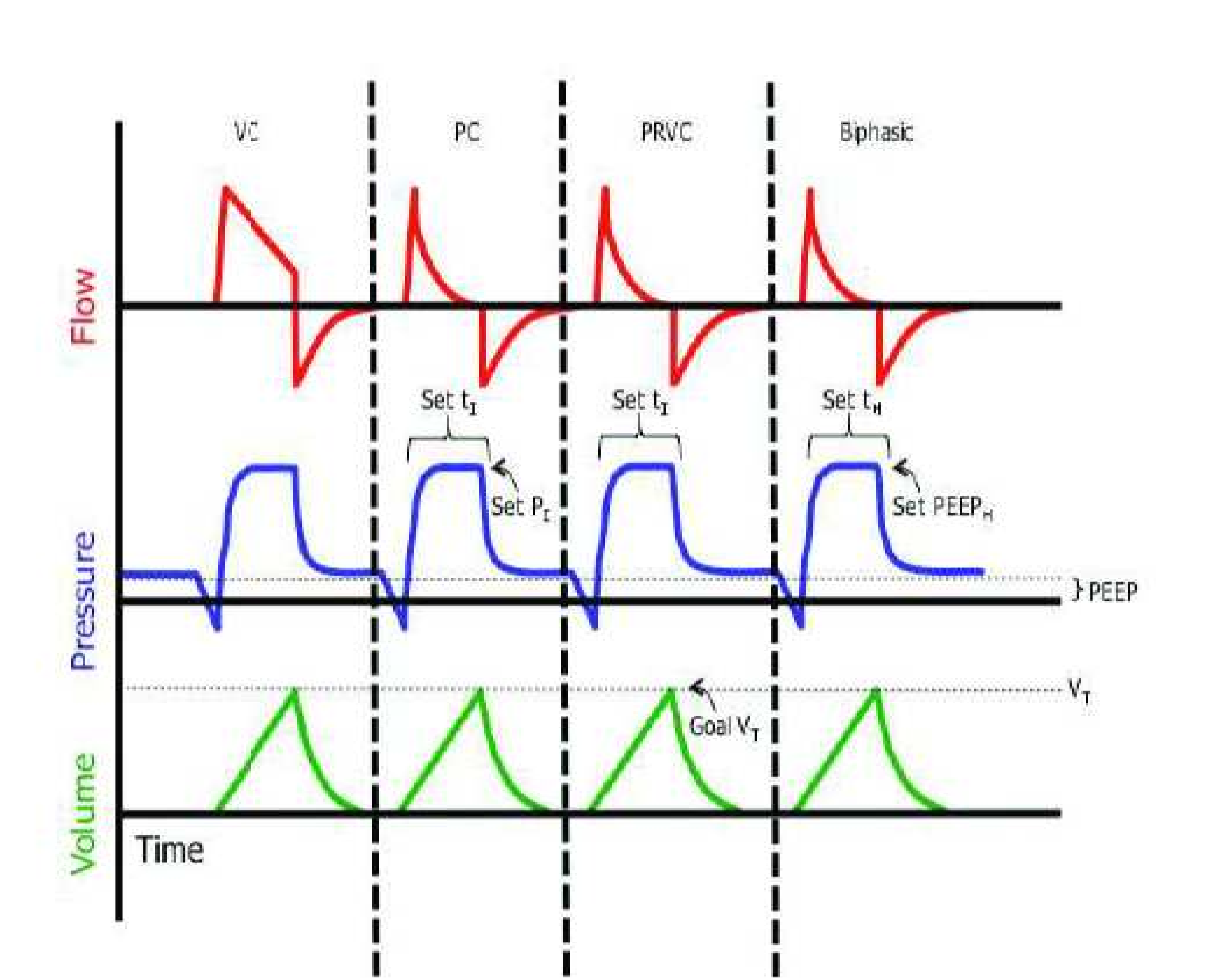
Airway Pressure Release Ventilation
APRV



Name that Mode

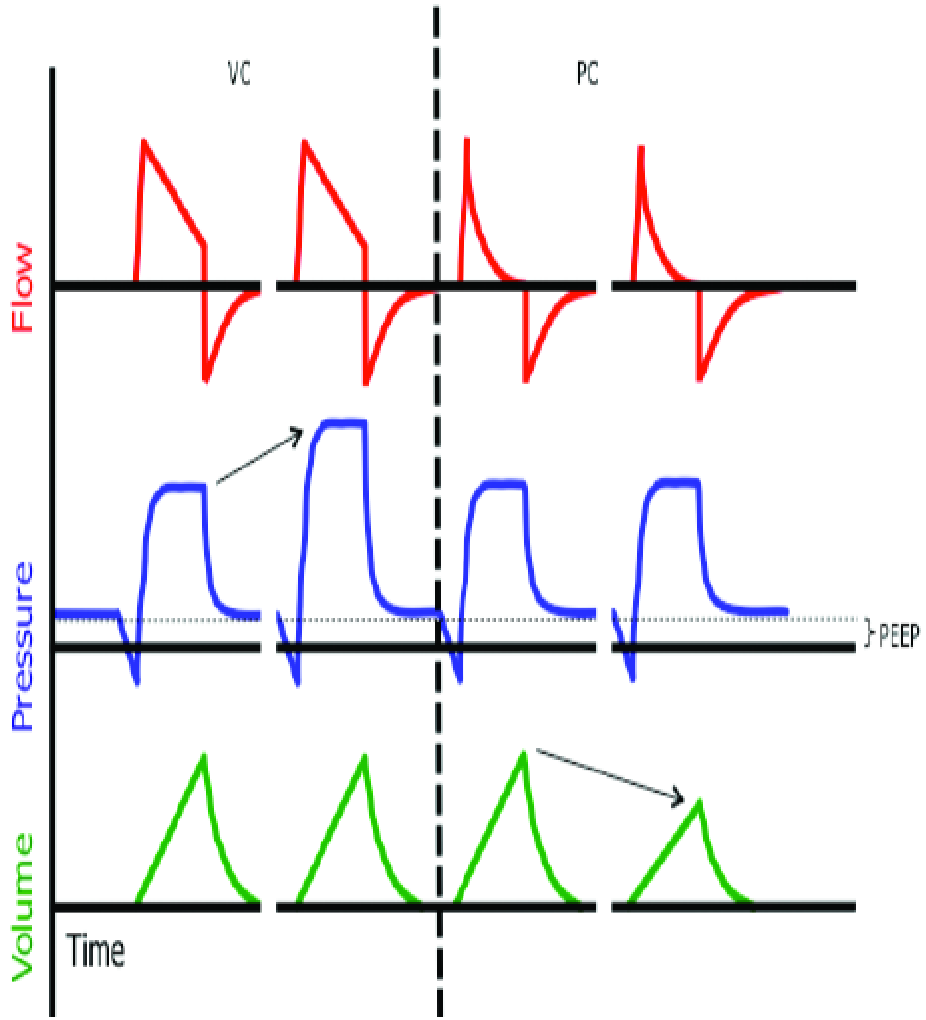


Name that Mode



What Happens When Respiratory System Mechanics Change?

Effects of a Drop in Resp System Static Compliance (Cstrs)



- When airway pressures, respiratory rate and inspiratory time are matched, changing modes is often seamless—such that pressure, flow and volume waveforms may look almost identical

- However, appropriate management presupposes an understanding of how the ventilator will respond to changes in patient mechanics

Selected Goals

- Optimize gas exchange
- Achieve patient-machine synchrony
- Decrease but not eliminate WOB
- Mitigate ventilator induced lung injury

Select Studies Comparing Modes

- SIMV vs AC in ARF: no difference in hemodynamic, metabolic, ventilatory or oxygenation variables[1]
- AC vs SIMV vs SIMV/PSV: SIMV/PSV increased minute ventilation and ventilatory equivalent compared to other modes[2]
- SIMV-PSV vs A/C: no difference in clinical outcomes, despite treatment-allocation bias that would have favored SIMV-PSV[3]
- APRV vs AC: no difference in mortality[4]

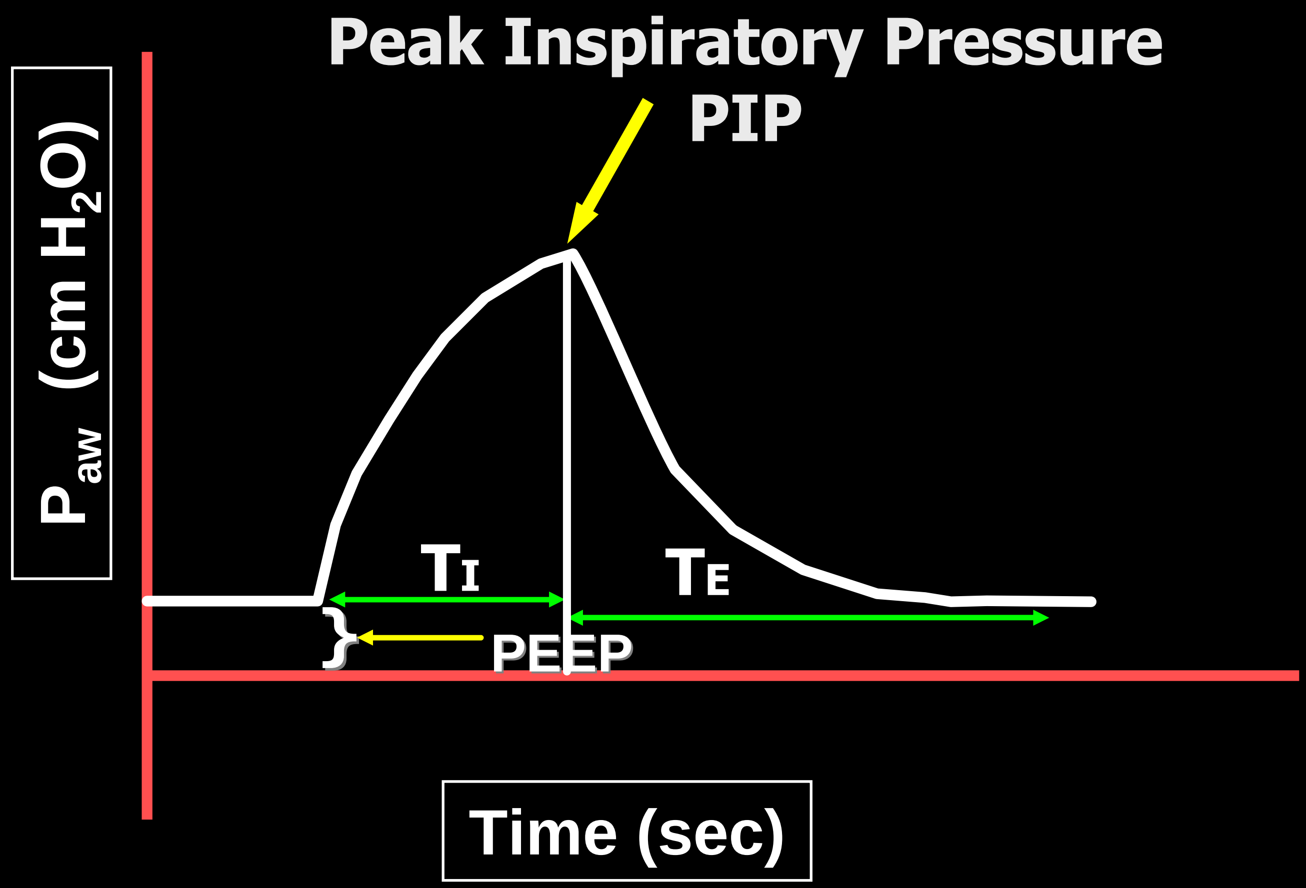
[1]Groeger JS, Crit Care Med 1989; 17: 607:
[2]Shelledy DC, Heart and Lung 1995; 24: 67
[3]Ortiz G, Chest 2010; 137: 1265
[4]Gonzalez M, Intensive Care Med 2010; 36: 817

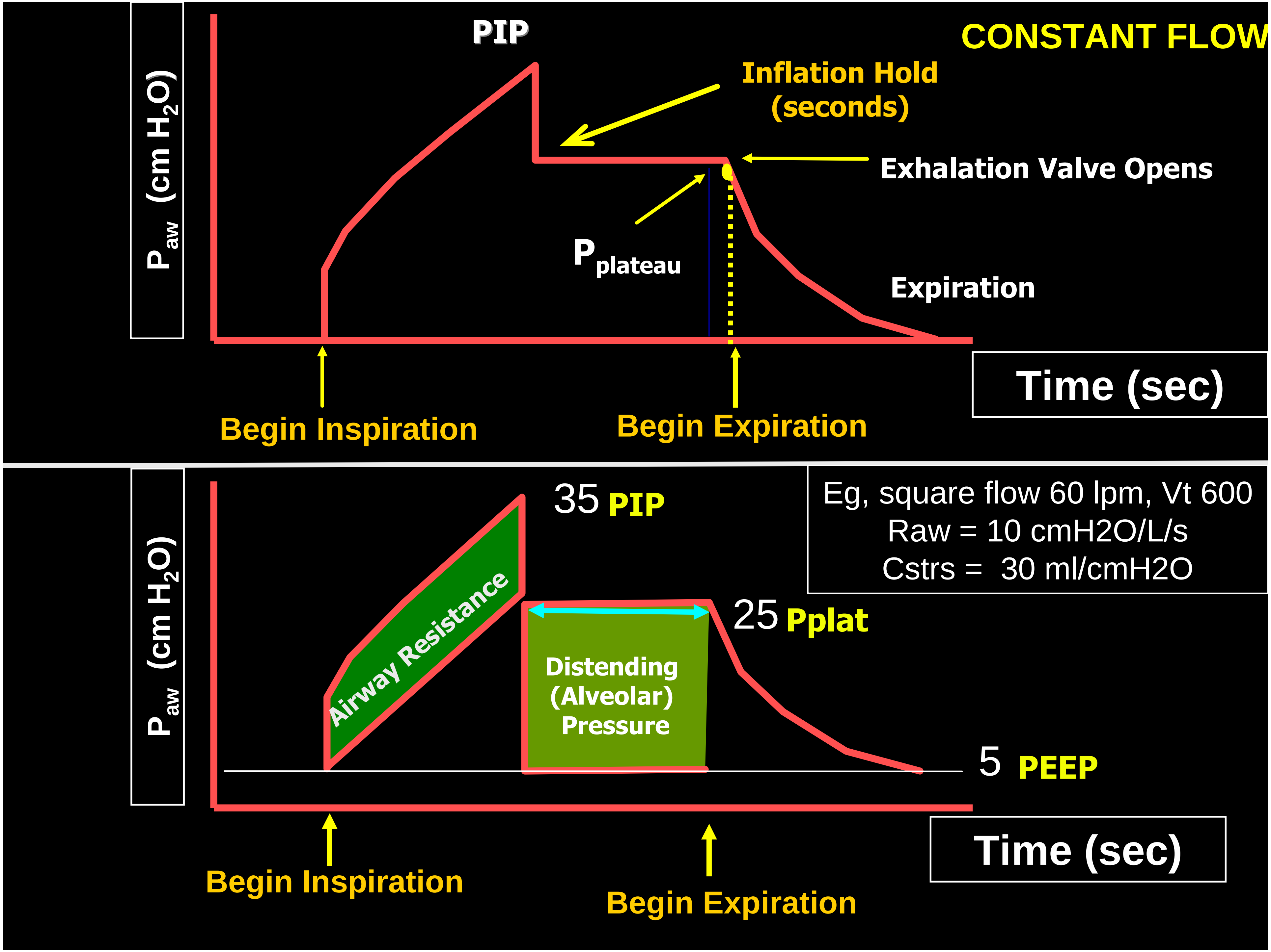
Evolution of MV 1998 -2004

- Noninvasive ventilation increased (11.1 vs. 4.4%, $P < 0.001$).
- In ARDS, tidal volumes decreased (7.4 vs. 9.1 ml/kg, $P < 0.001$) and positive end-expiratory pressure levels increased slightly (8.7 vs. 7.7 cm H(2)O, $P = 0.02$).
- More patients were successfully extubated after their first attempt of spontaneous breathing (77 vs. 62%, $P < 0.001$).
- Use of SIMV fell dramatically (1.6 vs. 11%, $P < 0.001$).

Esteban A, AJRCCM 2008; 177: 170

Pressure Waveform Analysis
Constant Flow





CONSTANT FLOW
PIP
Inflation Hold (seconds)
Exhalation Valve Opens
P plateau
Expiration
Paw (cm H2O)
Time (sec)
Begin Inspiration
Begin Expiration
Eg, square flow 60 lpm, Vt 600
Raw = 10 cmH2O/L/s
Cstrs = 30 ml/cmH2O
35 PIP
25 Pplat
5 PEEP
Airway Resistance
Distending (Alveolar) Pressure
Paw (cm H2O)
Time (sec)
Begin Inspiration
Begin Expiration

Mechanics

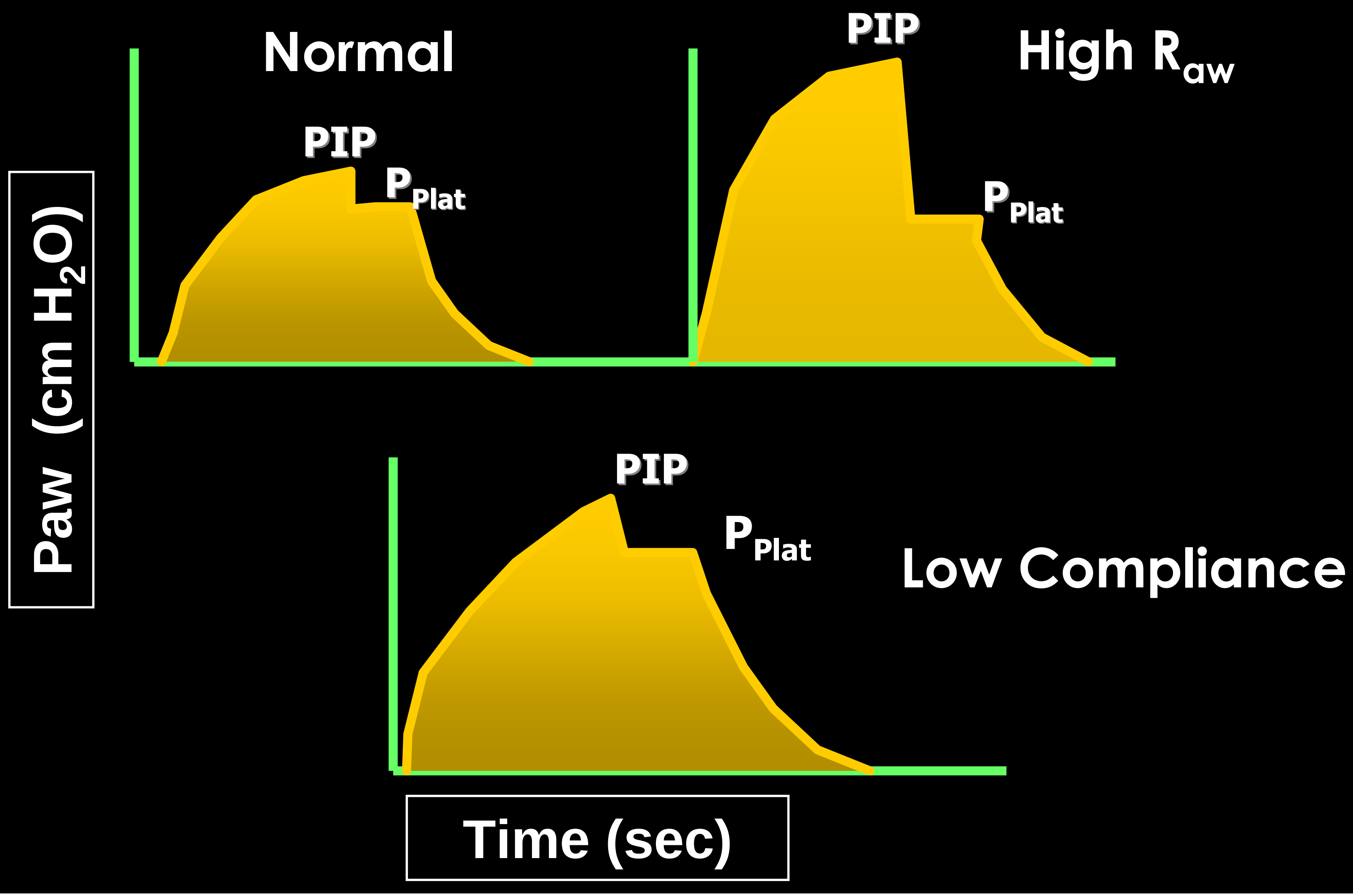
Airway Resistance (Raw)

- Square flow 60 L/min (1L/s)
- $\frac{\text{PIP - Pplat cmH}_2\text{O}}{\text{L/sec}}$
- Normal < 15 cmH_2O/L/sec
- Causes of increased Raw:
  - Occluded ETT
  - Secretions
  - Bronchospasm

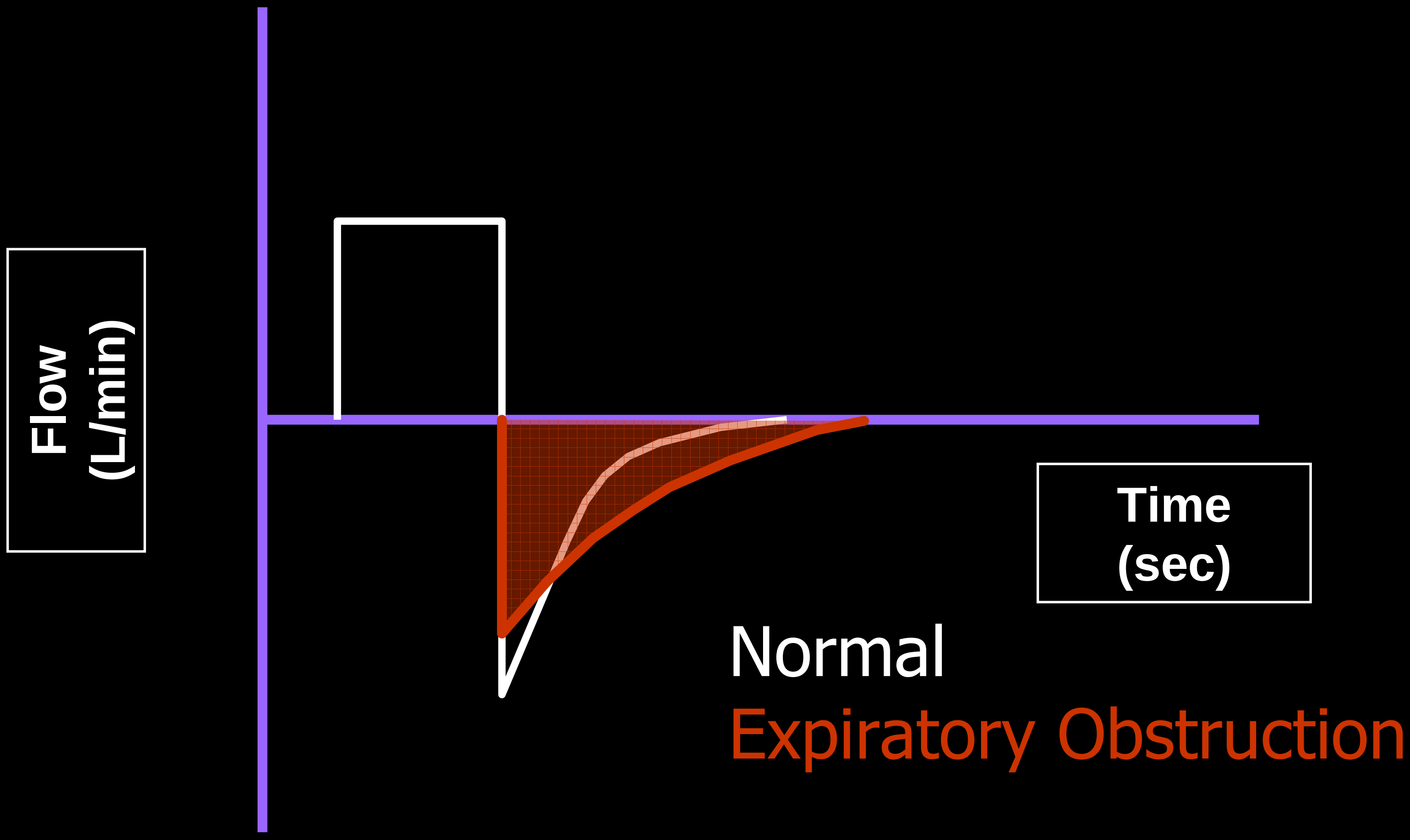
Static Compliance of the Respiratory System (Cstrs)

- C = Δ V/ Δ P
- Cstrs = (Vt)/(Pplat – PEEP)
- Normal 60 -80 ml/cmH_2O
- Causes of low compliance
  - Pulmonary edema
  - Pleural effusion
  - Pneumothorax
  - Right mainstem intubation
  - Tense abdomen
  - Hyperinflation

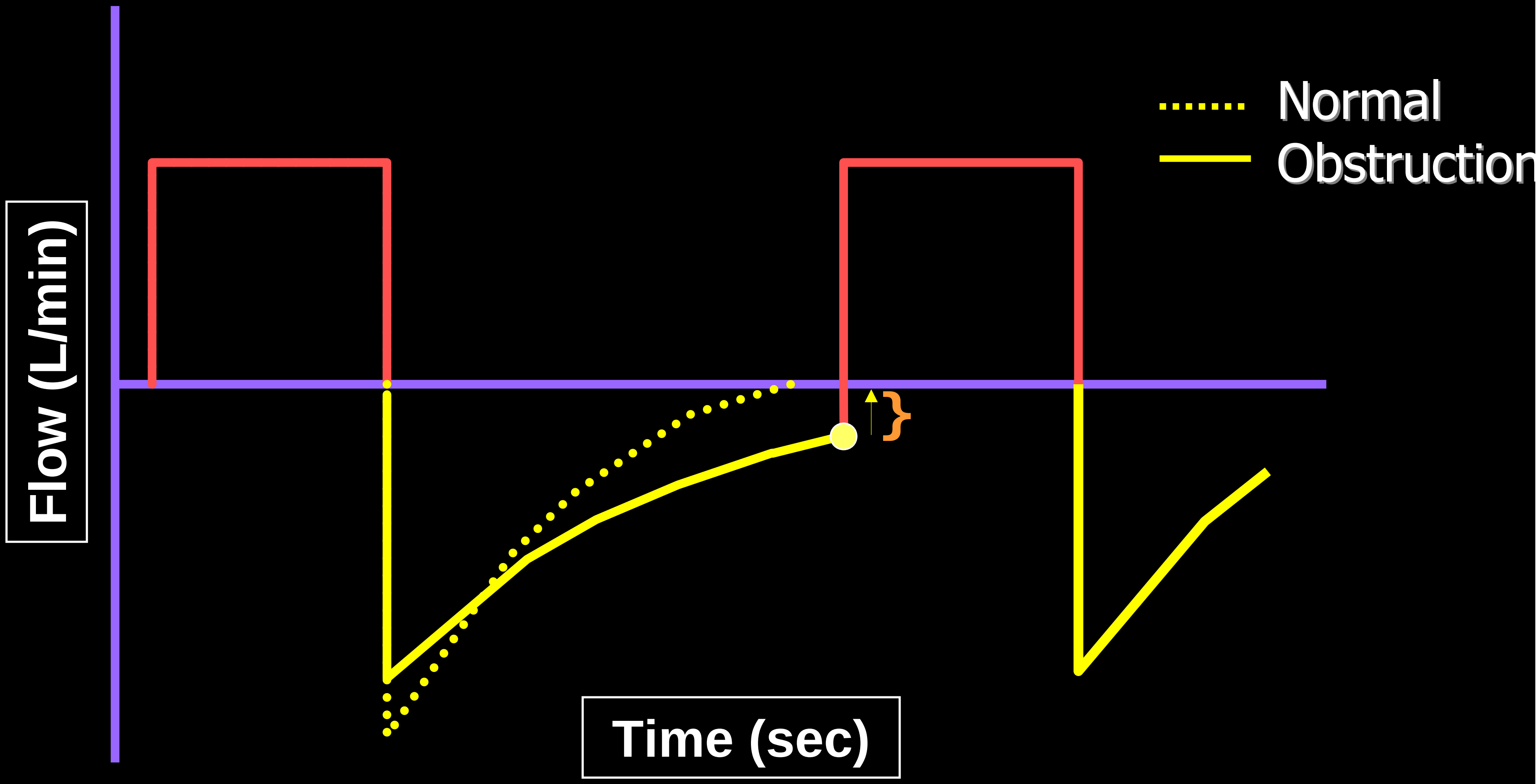
PIP vs P_{plat}


Normal
PIP
PPlat
High Raw
PIP
PPlat
Low Compliance
PIP
PPlat
Paw (cm H2O)
Time (sec)

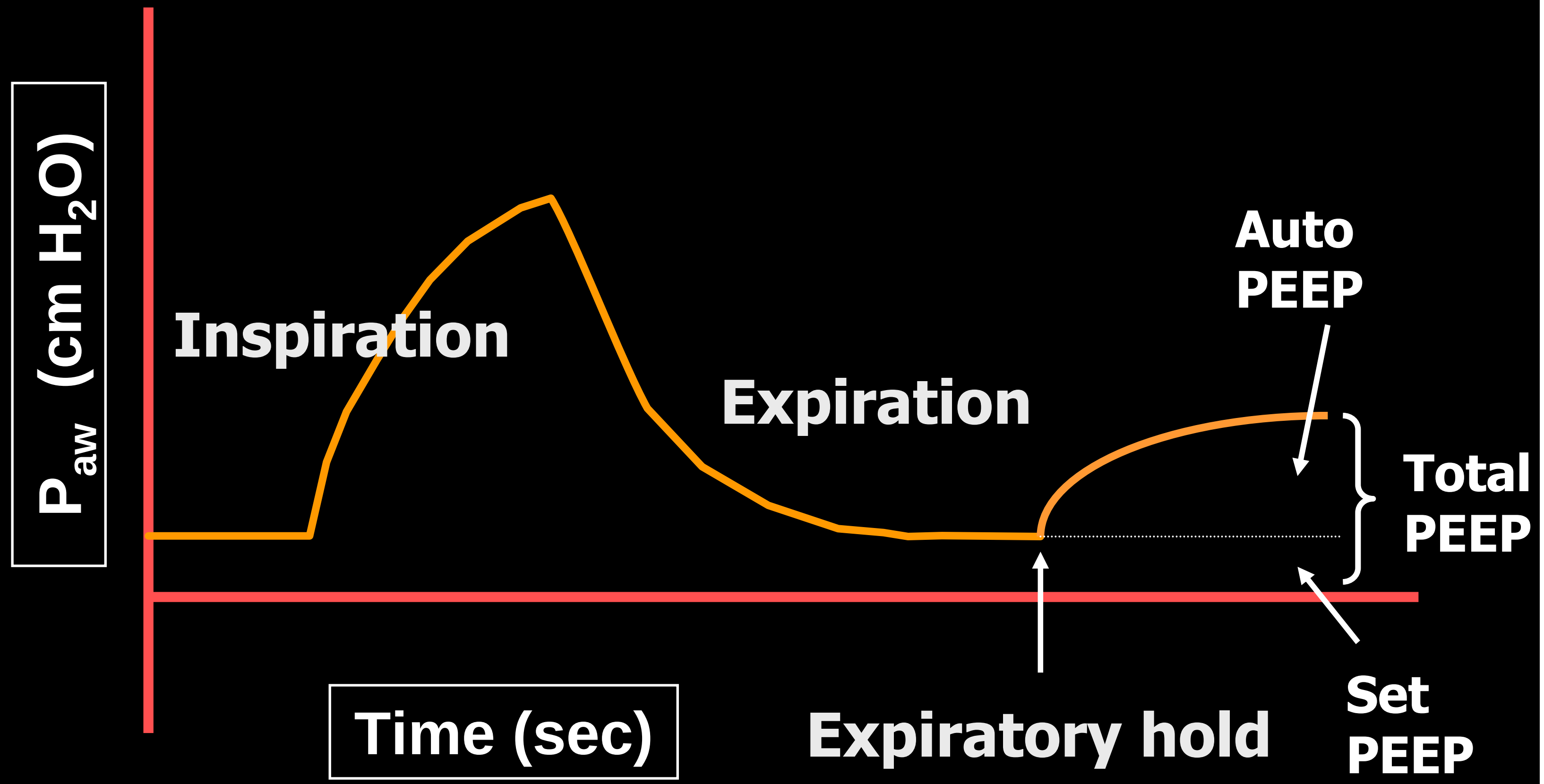
Normal vs Obstruction



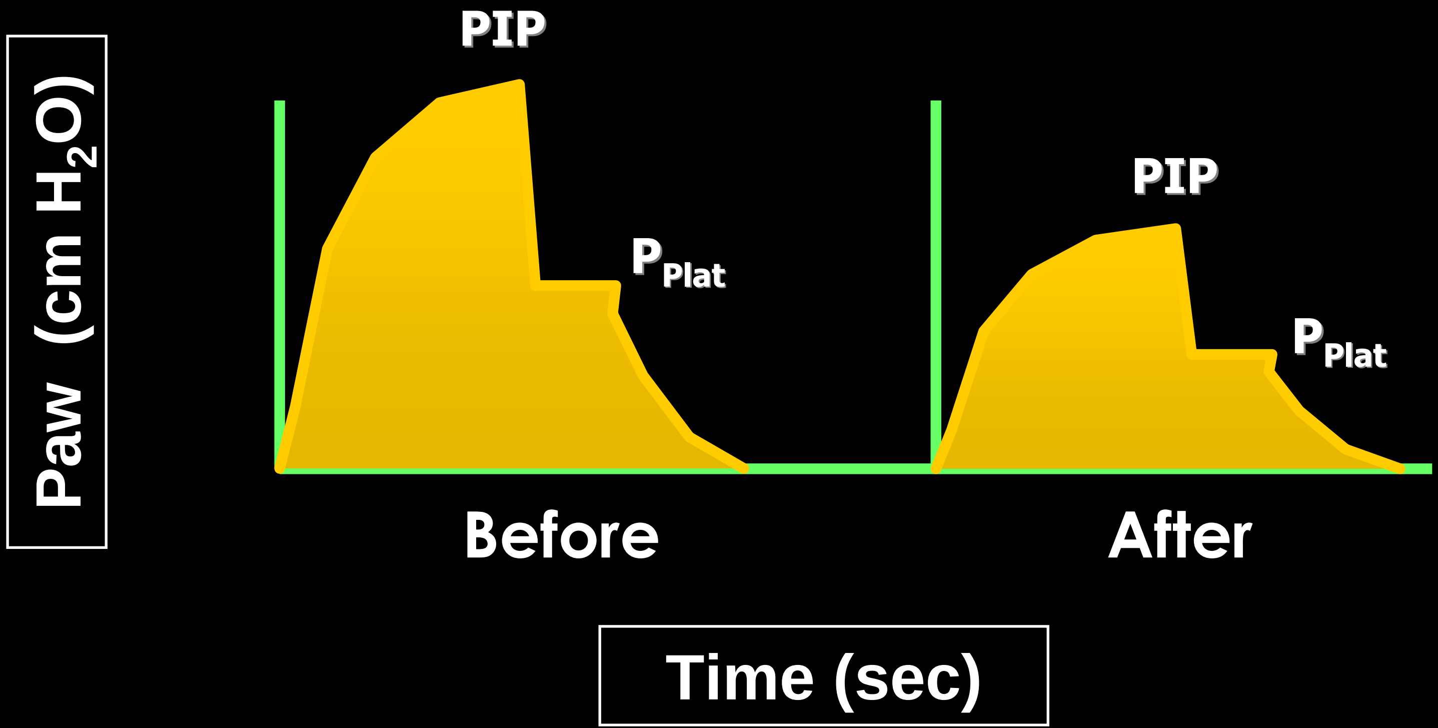
Normal vs. Expiratory Airflow Obstruction



Auto-PEEP Determination



Response to Bronchodilator



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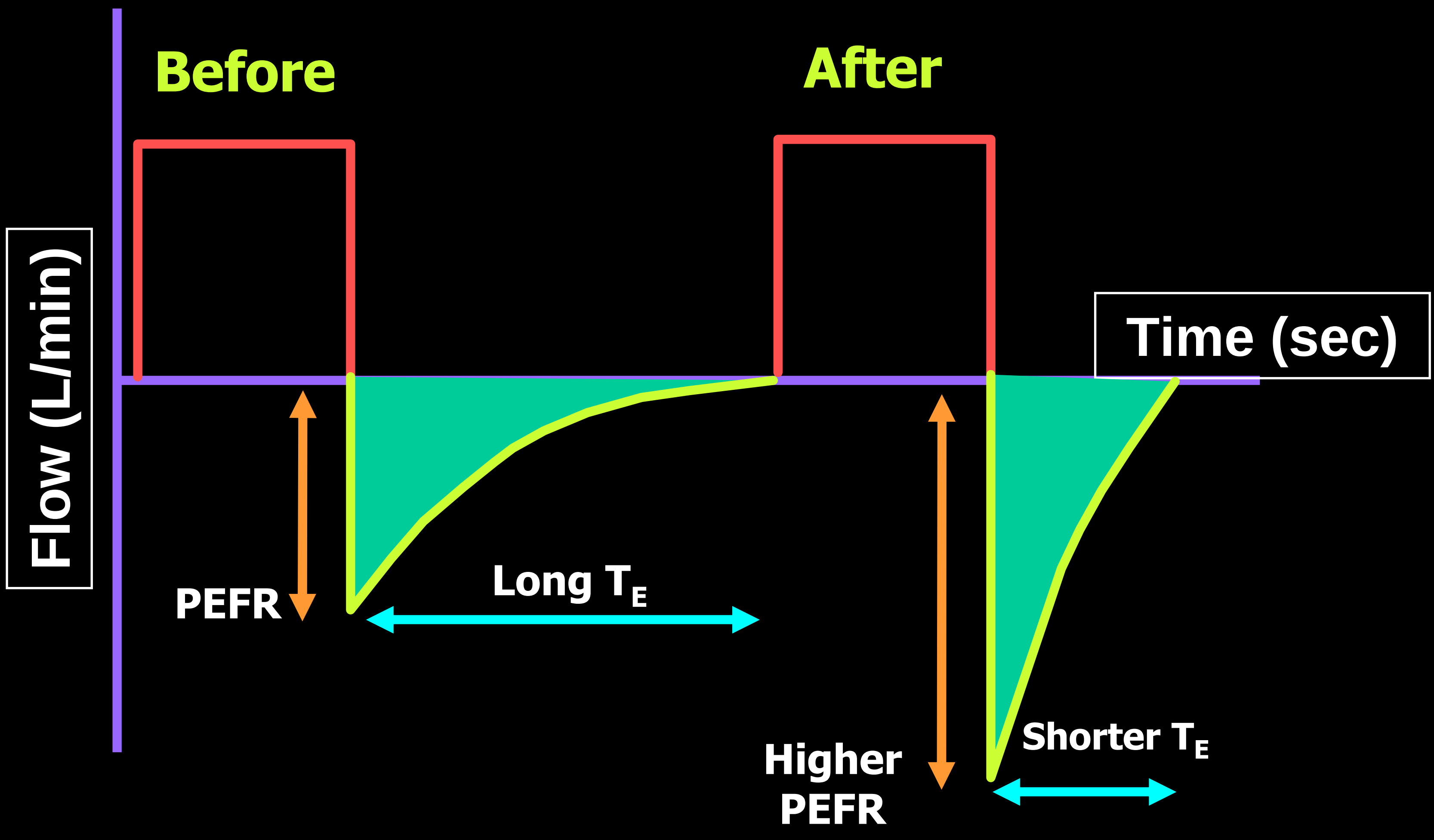
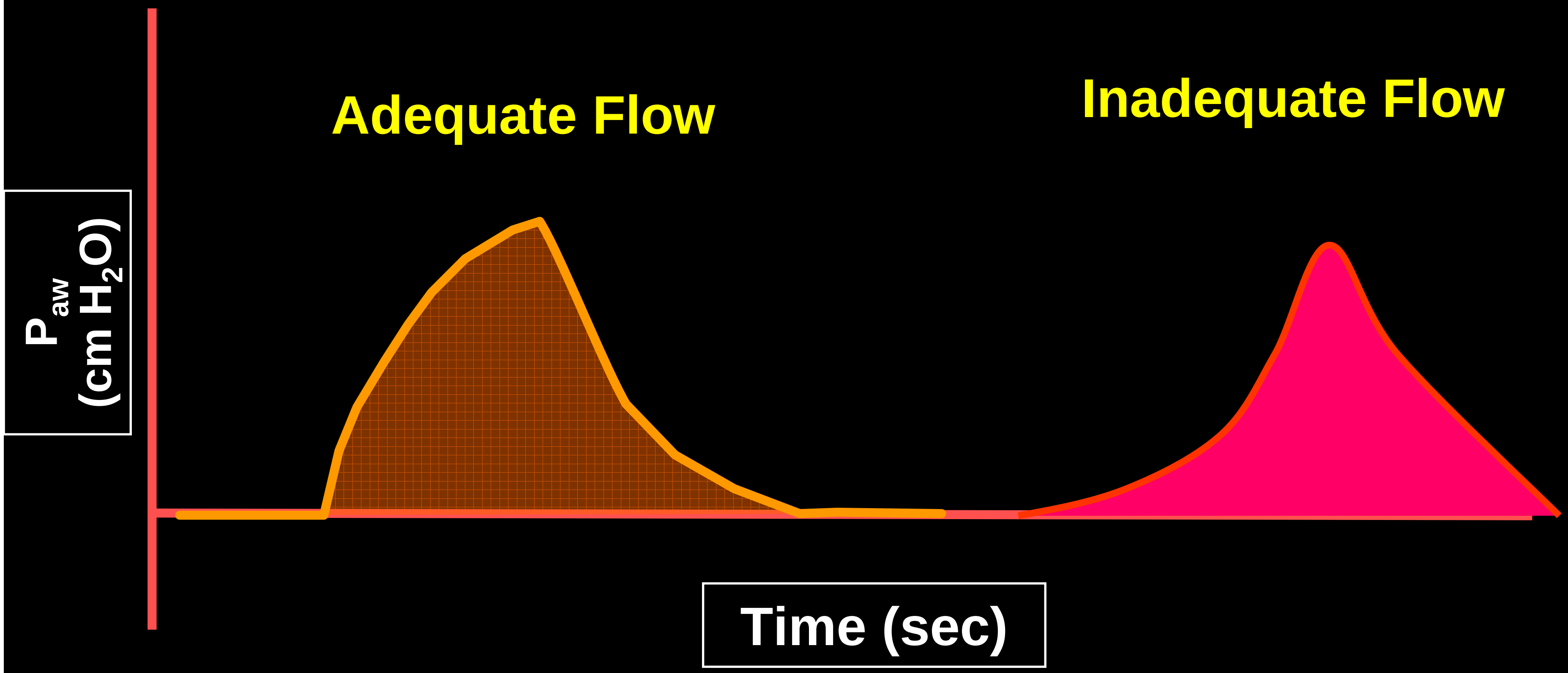


Inadequate Inspiratory Flow



Inadequate Inspiratory Flow

Active Inspiration or Asynchrony