Introduction of Mechanical Ventilation

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Outline

- Ventilator Need (Indications)
- Ventilator Operation
- Common Modes of Ventilation and Initial Settings
- Specific Disease Consideration
- Assessment and Trouble-Shooting

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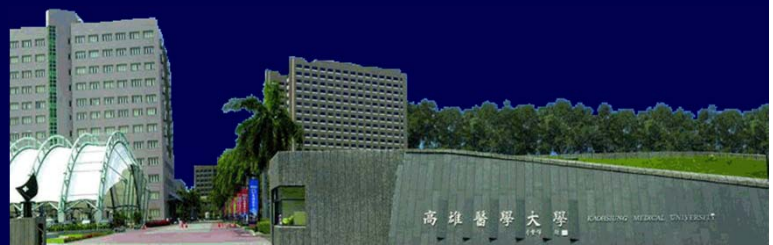

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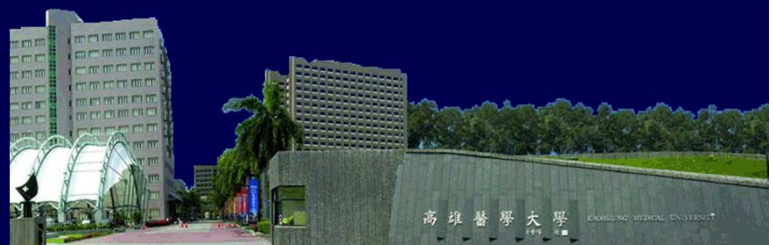

Physiologic aspects of MV

- Provide warmed and humidified air
- Serves as the energy source for inspiration
- Replacing the muscles of the diaphragms and chest wall
- Expiration:
  passive, by the recoil of the lungs and chest wall.
- Positive end-Expiratory pressure (PEEP)
  - Maintain patency of alveoli and small airways
  - 0-10 cmH_2O

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Respiratory Failure

inadequate blood oxygenation or CO_2 removal

A syndrome rather than a disease

PaO_2 < 60 mmHg or $PaCO_2$ > 50 mmHg

Hypoxemic

PaO_2 < 55~60 mmHg or SaO_2 < 90%
with FiO_2 ≥ 60%

Hypercapnic

$PaCO_2$ > 45~50 mmHg

This two types of respiratory failure almost always coexist!

Acute: develops in minutes to hours, pH < 7.30
Chronic: develops over several days or longer

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Indications for Mechanical Ventilation

- **Respiratory failure**: inadequate blood oxygenation or CO_2 removal
  - Hypoxemia: $PaO_2 < 55\sim60$ mmHg or $SaO_2 < 90\%$ with $FiO_2 \geq 60\%$
  - Hypercarpnia: $PaCO_2 > 45\sim50$ mmHg
- **Severe impaired gas exchange**
- An **inadequate response to less invasive medical treatment**
- **Increased work of breathing** with evidence of respiratory muscle fatigue
- Hyperventilation for **IICP**
- Prevent **aspiration** (absent gag or cough reflex)

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Types of Mechanical Ventilation

- Negative pressure ventilation vs. Positive pressure ventilation
- Non-invasive ventilation vs. Invasive ventilation
- Volume ventilation vs. Pressure ventilation
- Full ventilatory support vs. Partial ventilatory support

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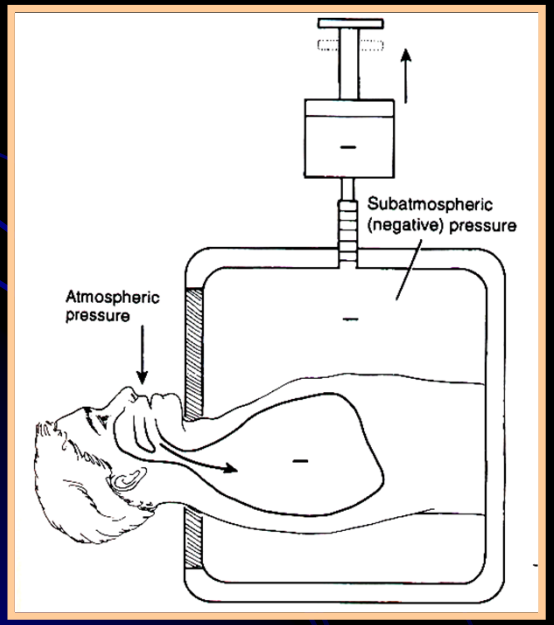
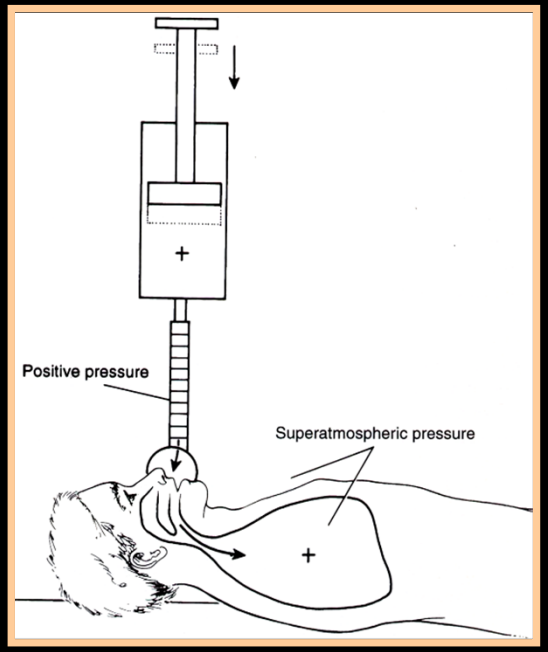
Methods of Assisted Ventilation

- **Negative pressure ventilation:**
  - exposure to negative extra-thoracic pressure
  - Iron lung/chest cuirass
  - Disadvantage: variable tidal volume, airway pressure, large machine volume



- **Positive pressure ventilation:**
  - Positive pressure to increase alveolar pressures
  - Advantage: precise tidal volume, airway pressure, … etc.
  - Invasive: intubation
  - Non-invasive (NIPPV)



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Iron lung

- Iron lung ward filled with polio patients, Rancho Los Amigos Hospital, California (1953)

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http://en.wikipedia.org/wiki/Iron_lung

Non-Invasive Positive Pressure Ventilation

- **Indications** of NIPPV for Acute Respiratory Failure:
  - **Strong evidence** (multiple controlled trials):
    - COPD exacerbations
    - Acute cardiogenic pulmonary edema
      - Evidence strongest for CPAP
    - Immunocompromised patients
    - Facilitation of weaning in COPD patients
  - **Less strong evidence** (single controlled trial or multiple case series):
    - Asthma
    - Cystic fibrosis
    - Postoperative respiratory failure
    - Avoidance of extubation failure
    - DNI patients

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[Chest 2003;124;699-713]

Non-Invasive Positive Pressure Ventilation

- **Indications** of NIPPV for Acute Respiratory Failure:
  - **Weak evidence** (few case series or case reports):
    - Upper airway obstruction
    - Acute respiratory distress syndrome (ARDS)
    - Trauma
    - Obstructive sleep apnea, obesity hypoventilation

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[Chest 2003;124;699-713]

Non-Invasive Positive Pressure Ventilation

- **Contraindications**:
  - Respiratory arrest
  - Medically unstable
  - Unable to protect airway
  - Excessive secretions
  - Uncooperative or agitated
  - Unable to fit mask
  - Recent upper airway or gastrointestinal surgery

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[Chest 2003;124;699-713]

NIV Contraindications

- **Absolute contraindications**
  - Respiratory arrest
  - Cardiac arrest
  - Nonrespiratory organ failure (eg., severe encephalopathy, severe gastrointestinal bleeding or surgery, hemodynamic instability with or without unstable cardiac angina)
  - Upper airway obstruction
  - Inability to protect the airway or high risk of aspiration (for both)
  - Inability to clear secretions
  - Facial or head surgery or trauma
- **Relative contraindications**
  - Cardiovascular instability (hypotension, dysrhythmias, acute myocardial infarction)
  - Uncooperative patient (impaired mental status, hypersomnolence)
  - Copious or viscous secretions
  - Fixed nasopharyngeal abnormalities
  - Extreme obesity

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[Pilbeam SP, Cairo JM. 2015. Mechanical Ventilation: physiological and clinical applications, 6th ed.]

NIV changed to Invasive Ventilation

- Respiratory arrest
- Respiratory rate > 35 breaths/min
- Severe dyspnea with use of accessory muscles and possibly paradoxical breathing
- Life-threatening hypoxemia:
  PaO_2 < 40 mm Hg or PaO_2/FIO_2 < 200
- Severe acidosis (pH < 7.25) and hypercapnia ($PaCO_2$ > 60 mmHg)
- Hypersomnolence, impaired mental status
- Cardiovascular complications (hypotension, shock, heart failure)
- Failure of noninvasive positive pressure ventilation
- Other circumstances
  (e.g., metabolic abnormalities, sepsis, pneumonia, pulmonary embolism, barotrauma, massive pleural effusion)

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Official ERS/ATS clinical practice guidelines: noninvasive ventilation for acute respiratory failure

Clinical indication (in the setting of acute respiratory failure)	Certainty of evidence¶	Recommendation
Prevention of hypercapnia in COPD exacerbation	⊕⊕	Conditional recommendation against
Hypercapnia with COPD exacerbation	⊕⊕⊕⊕	Strong recommendation for
Cardiogenic pulmonary oedema	⊕⊕⊕	Strong recommendation for
Acute asthma exacerbation		No recommendation made
Immunocompromised	⊕⊕⊕	Conditional recommendation for
De novo respiratory failure		No recommendation made
Post-operative patients	⊕⊕⊕	Conditional recommendation for
Palliative care	⊕⊕⊕	Conditional recommendation for
Trauma	⊕⊕⊕	Conditional recommendation for
Pandemic viral illness		No recommendation made
Post-extubation in high-risk patients (prophylaxis)	⊕⊕	Conditional recommendation for
Post-extubation respiratory failure	⊕⊕	Conditional recommendation against
Weaning in hypercapnic patients	⊕⊕⊕	Conditional recommendation for

¶: certainty of effect estimates: ⊕⊕⊕⊕, high; ⊕⊕⊕, moderate; ⊕⊕, low; ⊕, very low.

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[Eur Respir J 2017; 50: 1602426]

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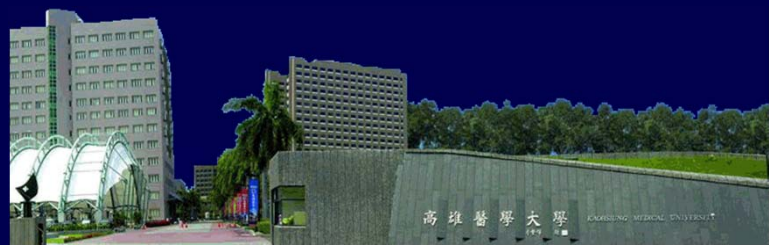

Major Parameters of MV

- Mode
- FiO_2
- Minute volume (V_E): $V_E = V_T * f$
  - Tidal volume (V_T)
  - Rate (RR, f)
- PEEP (positive end-expiratory pressure)
- I:E ratio
  - Inspiratory time (T_I)
  - Expiratory time (T_E)
- Trigger sensitivity
- Alarms

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FiO_2

- Initially, set FiO_2 as 100%.
- Maintain the FiO2 ≦60% to reduce the risk of oxygen toxicity.
- 100%氧氣暴露時間與生理反應:
  - 0～12小時 → 正常肺功能、氣管支氣管炎、胸骨下胸痛
  - 12～24小時 → 肺活量減少
  - 24～30小時 → 減低肺可張性、$P(A\text{-}a)O_2$增大、運動時PO_2下降
  - 30～72小時 → 減少擴散容積

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Minute ventilation

- Minute ventilation (minute volume):
  $\dot{V}_E = V_T \times f_b$ (tidal volume × respiratory rate)
  - Initial tidal volume: ~8 mL/kg
    - Use ideal body weight!
  - Respiratory rate: 10-15 cpm
- Adjust the minute ventilation to achieve **the patient's baseline $PaCO_2$**, not a normal $PaCO_2$

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Positive End-Expiratory Pressure

- **Definition:**
  maintenance of positive airway pressure at the end of expiration.
- Increases lung compliance and oxygenation while decreasing the shunt fraction and the work of breathing.
  - ARDS
  - Chest trauma
  - Postoperative atelectasis
  - Cardiopulmonary edema
  - Auto-PEEP
  - Artificial airway: 5 cmH_2O

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Positive End-Expiratory Pressure

- Increase peak and mean airway pressure and intrathoracic pressure
  - Decrease venous return and cardiac output
- Intracranical pressure:
  - Used cautiously in IICP patients
- Not to remove PEEP abruptly for it can result in collapse of distal lung units, the worsening of shunt and life-threatening hypoxemia.

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I:E Ratio

- Physiological: 1:2
- Set T_I in some machines

- e.g.: RR = 20, T_I = 1 sec
  → T_E = 2 sec, I:E = 1:2

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I:E Ratio

- **Inverse ration ventilation (IRV)**
  - I:E ratio that is greater than the standard 1:2-1:3 ratio to stabilize terminal respiratory units.
  - Goal of IRV
    - Decrease peak airway pressure
    - To maintain adequate alveolar ventilation
    - Improve oxygenation
  - Need sedation and often muscle paralysis.
  - Indications:
    - PaO_2 < 60 mmHg with FiO_2 of greater than 60%.
    - Peak airway pressure greater than 40-45 cmH_2O.
    - Need for PEEP of greater than 15 cmH_2O.

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Trigger sensitivity

- Pressure trigger
  - -1 ～ -2 cmH_2O
- Flow trigger (flow-by):
  - 2 ～ 3 L/min
  - more response than are pressure triggered system and result in a decreased work of breath.

- Difficult to trigger in the presence of **auto-PEEP**
  - Increase the flow (reducing T_I)
  - Reducing minute volume (reducing V_T or rate)
  - Suctioning the patient
  - Changing modes to allow for more spontaneous breath
  - Addition of extrinsic PEEP

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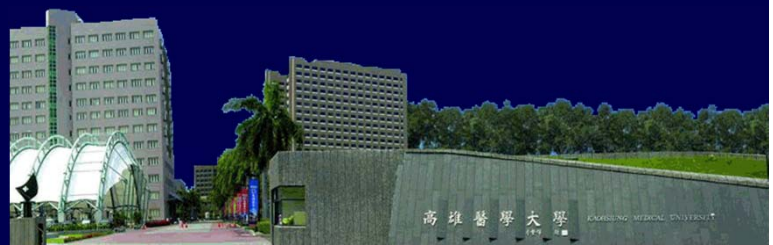

Mode

- Definition:
  - How a ventilator ventilates a patient.
  - Breath types given or allowed.
  - 病人與呼吸器間交互作用
    完成一個呼吸器通氣循環（ventilator cycle）
    的方法。

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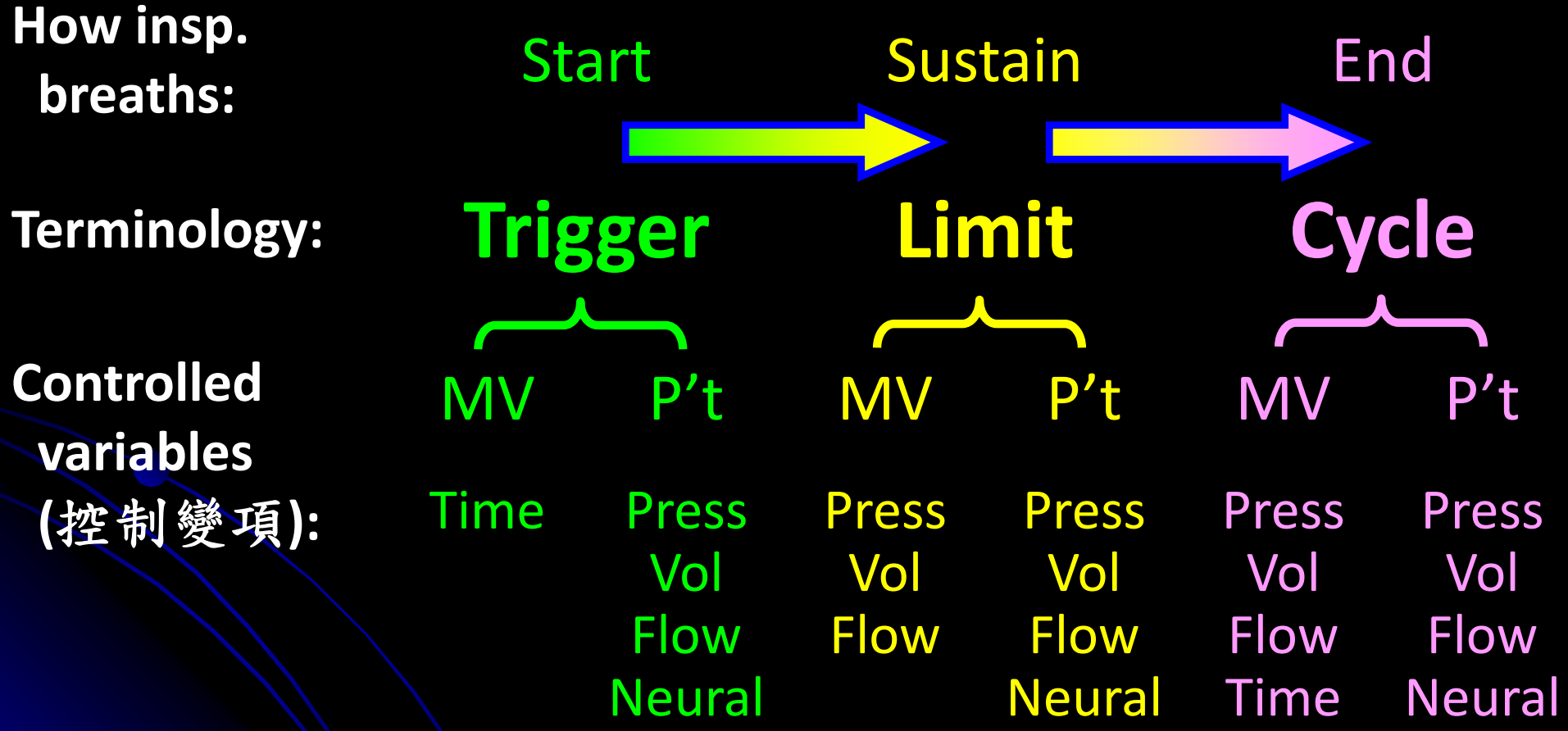
Mode

- Classification:



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Mode → Breath

- Breath types:

	Inspiratory phase variables		
	Trigger	**Limit**	**Cycle**
Machine-cycled breaths:			
Mandatory (control) breath	Machine-triggered	Machine-limited	Machine-cycled
Assisted breath	Patient-triggered	Machine-limited	Machine-cycled
Patient-cycled breath:			
Supported breath	Patient-triggered	Machine-limited	Patient-cycled
Spontaneous breath	Patient-triggered	Patient-limited	Patient-cycled

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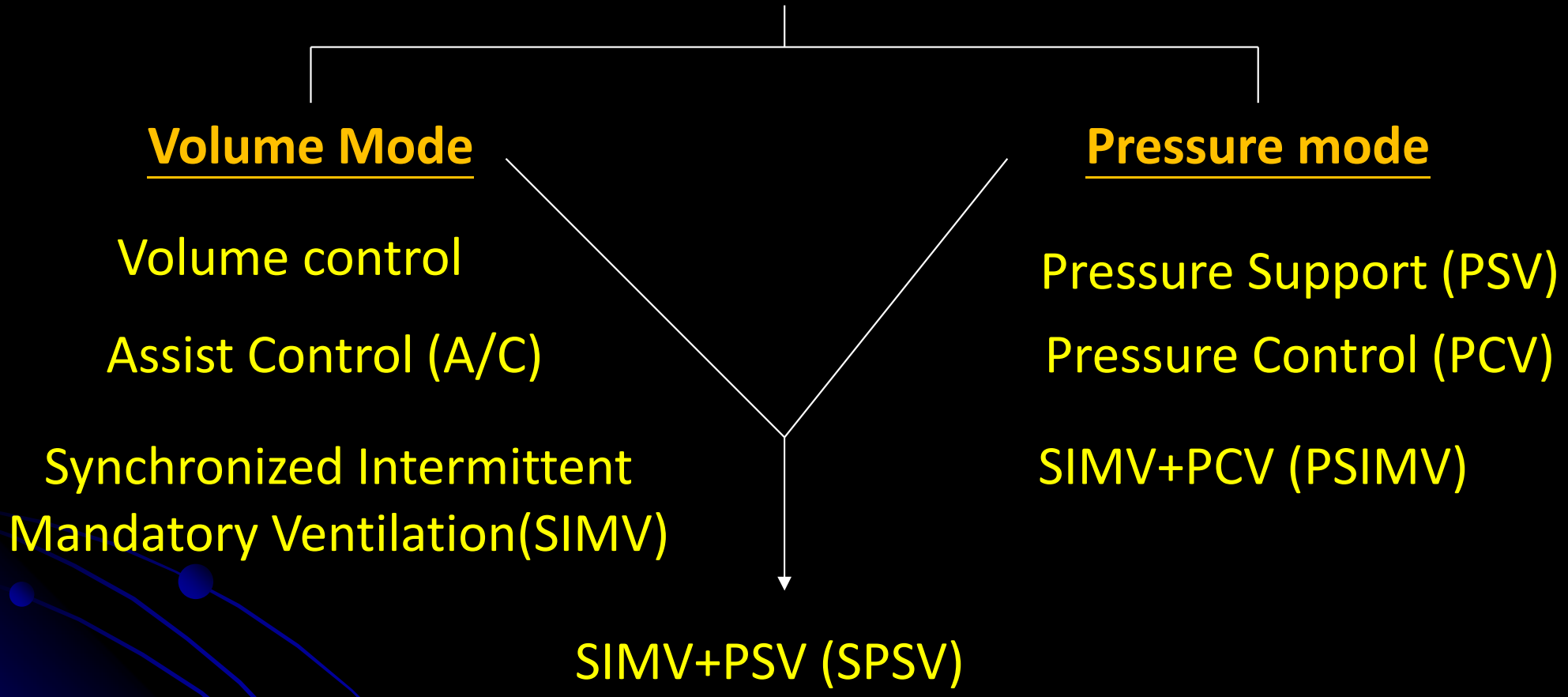
Positive Pressure Ventilation



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Positive Pressure Ventilation

Continuous	Intermittent	Spontaneous
Continuous Mandatory Ventilation (CMV)	Intermittent Mandatory Ventilation (IMV)	
Assist Control (A/C)	Synchronized IMV (SIMV)	
Volume Control (VCV)	SIMV (+PSV)	Pressure Support (PSV)
Pressure Control (PCV)	PSIMV (+PSV)	Continuous Positive Airway Pressure (CPAP)

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Volume Assistant/Control (VC, A/C)

- Independent variable (set by user)
  - FiO_2, tidal volume, rate, PEEP, inspiratory flow pattern, peak inspiratory flow, pressure limit
- Dependent variables
  - Peak airway pressure, PaO_2, $PaCO_2$, mean airway pressure, I/E ratio
- Trigger/cycle limit
  - Patient/timer, flow limit
- Advantage
  - Timer backup, patient-ventilator synchrony, patient controls minute ventilation
- Disadvantages
  - Not useful weaning, potential dangerous respiratory alkalosis
- Initial setting
  - FiO_2: 100%, V_T = 10-15 ml/kg, f = 12-15/min, PEEP = 0-5 cmH_2O
  - Inspiratory flow =60 L/min

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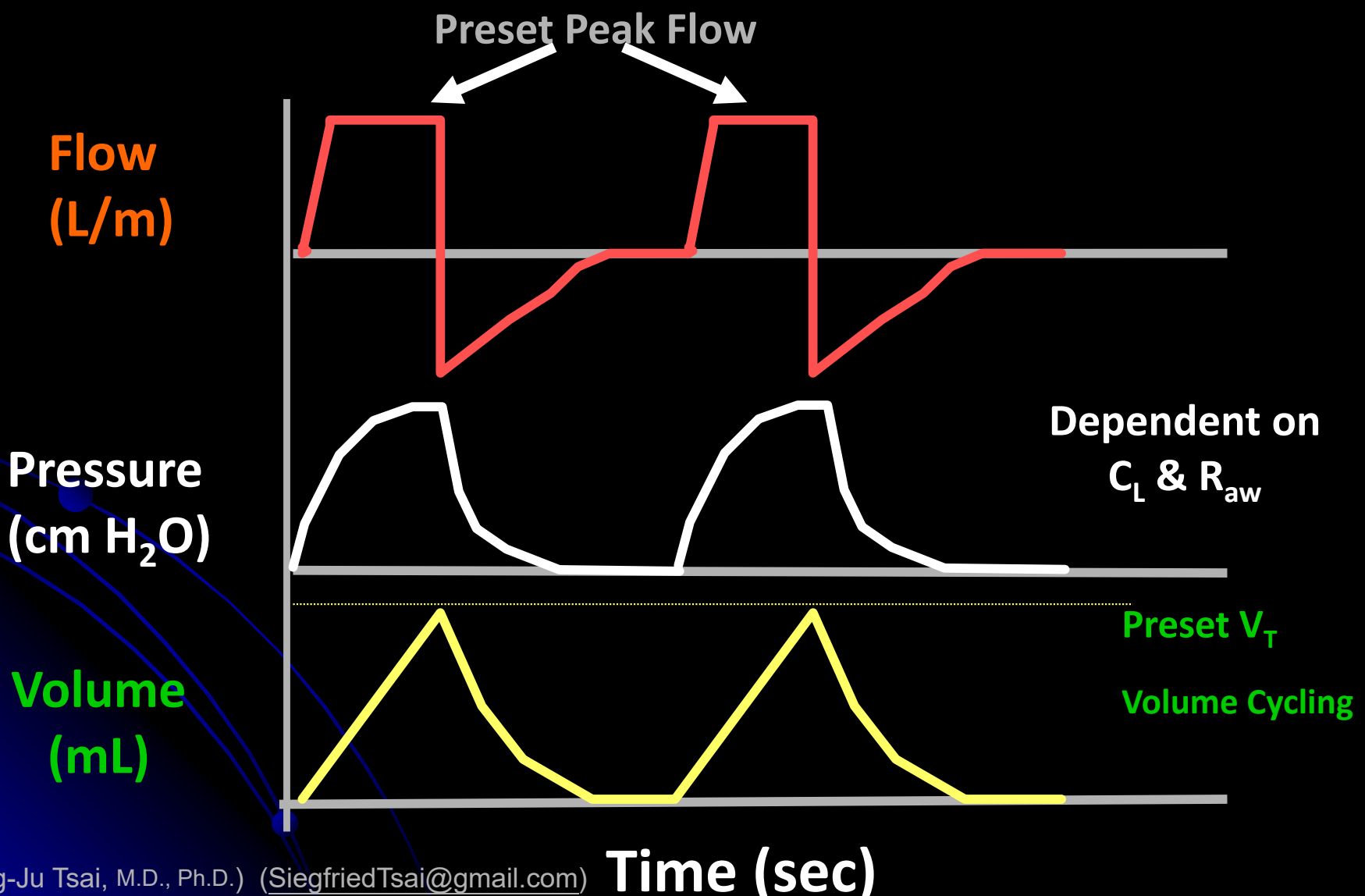
Controlled Mode (volume-targeted ventilation)

Time triggered, Flow limited, Volume cycled Ventilation



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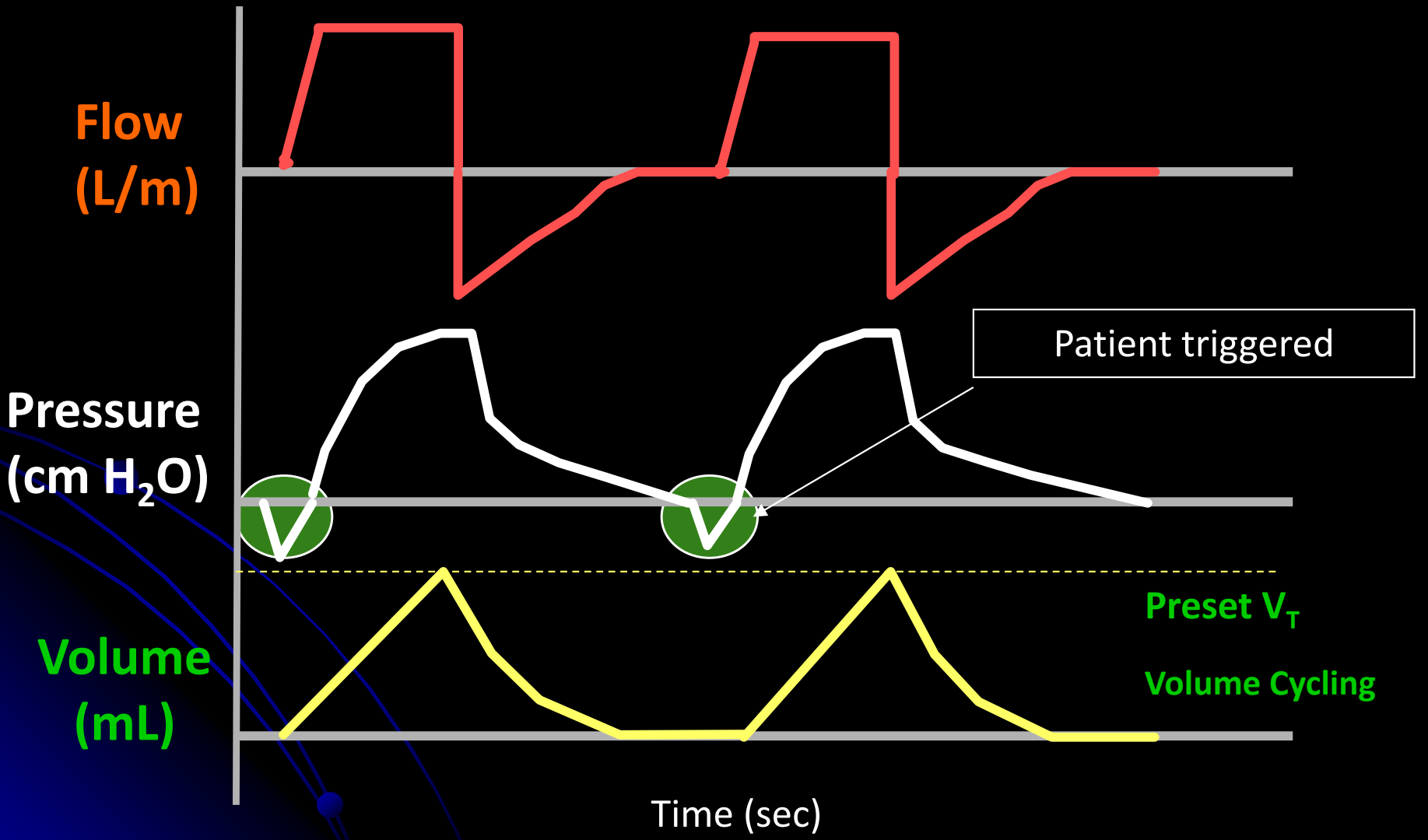
Assisted Mode (volume-targeted ventilation)

Patient triggered, Flow limited, Volume cycled Ventilation



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Pressure Control (PC)

- Independent variable (set by user)
  - FiO_2, inspiratory pressure level, rate, PEEP, pressure limit, I/E ratio
- Dependent variables
  - Tidal volume, flow rate, pattern, minute ventilation, PaO_2, $PaCO_2$
- Trigger/cycle limit
  - Time/patient, time/pressure limit
- Advantage
  - System pressures regulated, useful for barotrauma treatment, timer backup
- Disadvantages
  - Requires heavy sedation
- Initial setting
  - FiO_2: 100%, PC = 20-40 cmH_2O, f = 12-15/min, PEEP = 5-10 cmH_2O
  - I/E : 0.7/1- 4/1

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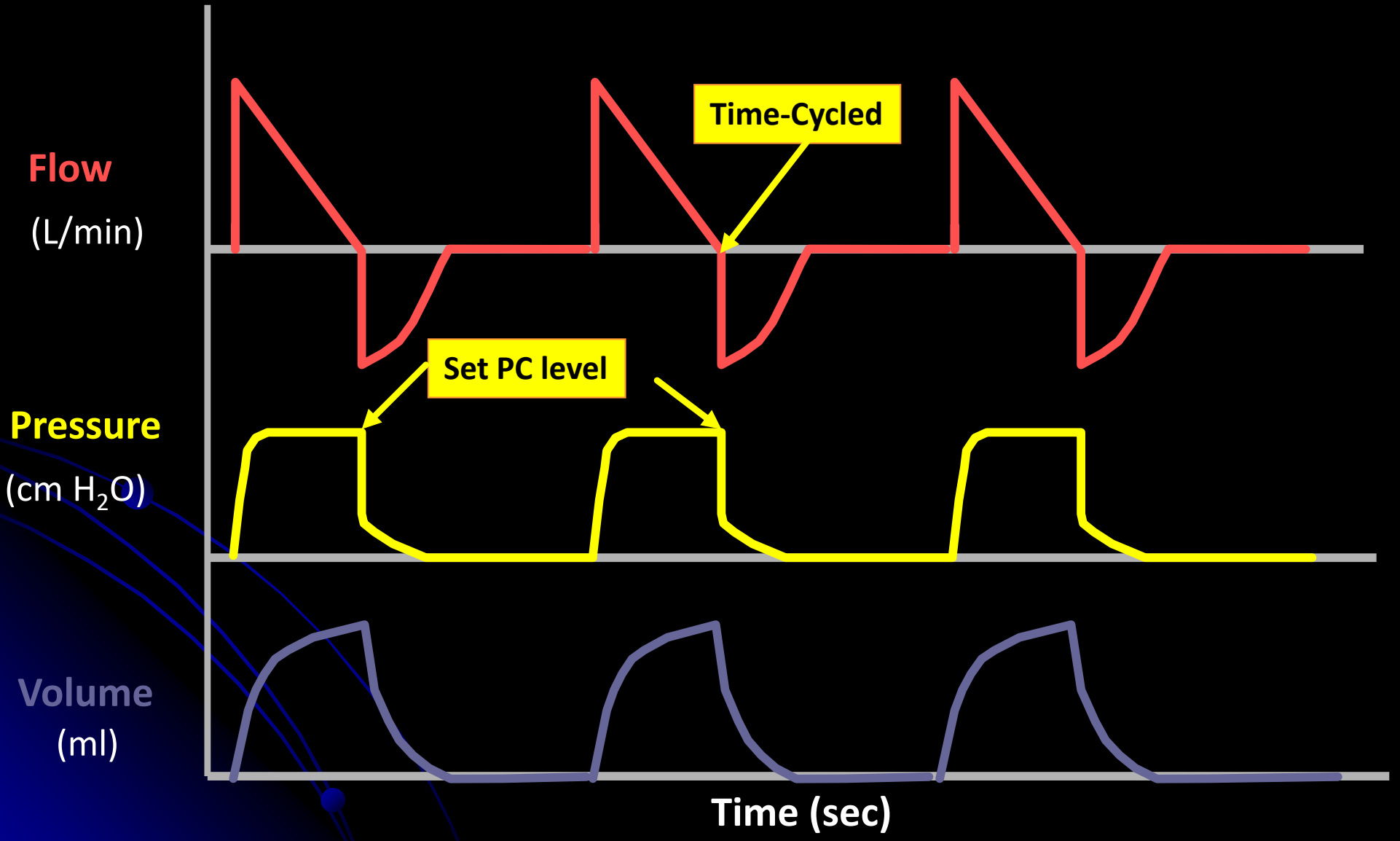
Controlled Mode (pressure-targeted ventilation)

Time Triggered, Pressure Limited, Time Cycled Ventilation



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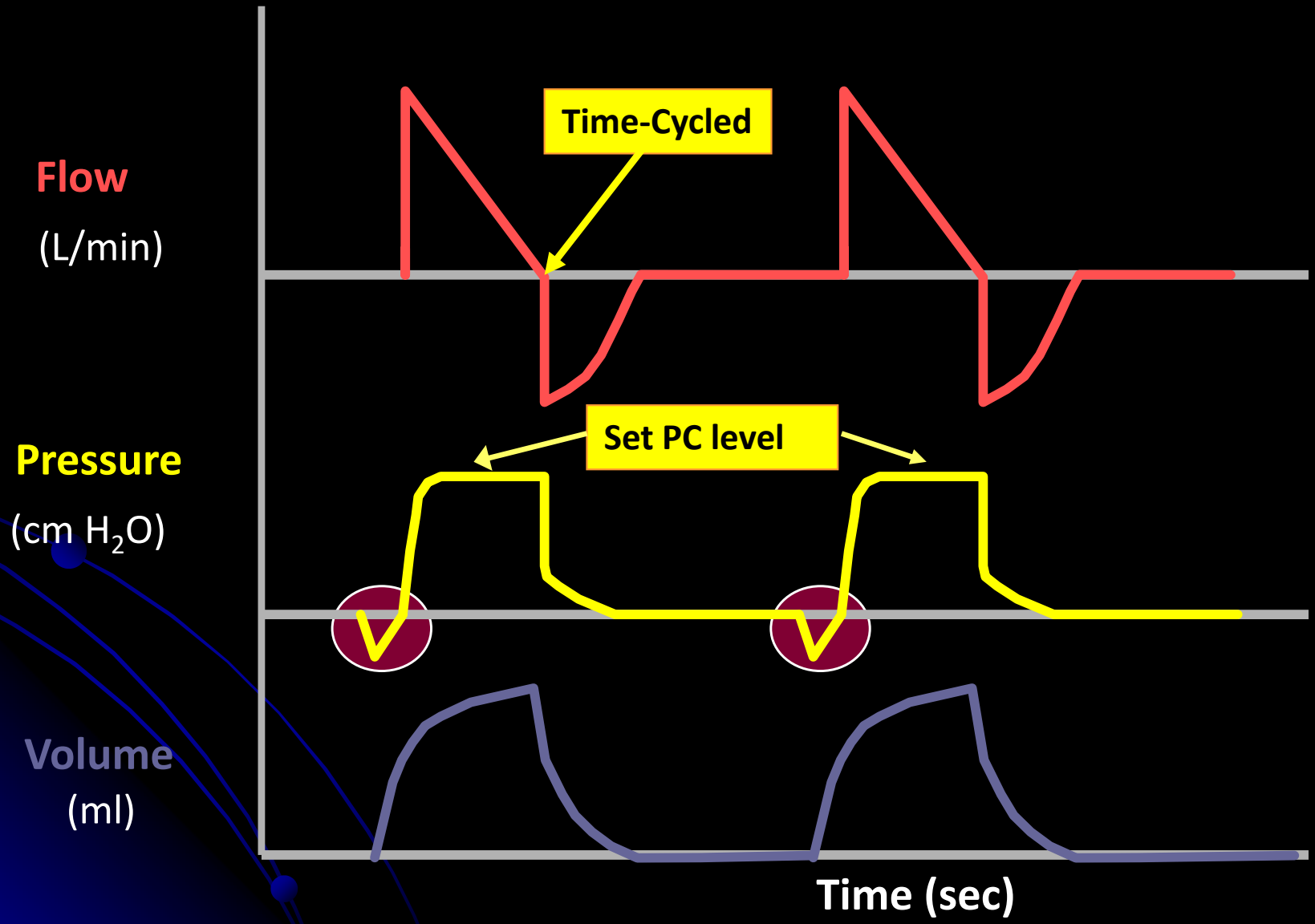
Assisted Mode (pressure-targeted ventilation)

Patient Triggered, Pressure Limited, Time Cycled Ventilation



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Synchronized Intermittent Mandatory Ventilation (SIMV)

- Independent variable (set by user)
  - FiO_2, tidal volume, rate, PEEP, inspiratory flow pattern, peak inspiratory flow, pressure limit
- Dependent variables
  - Peak airway pressure, PaO_2, $PaCO_2$, mean airway pressure, I/E ratio
- Trigger/cycle limit
  - Patient/timer, pressure/flow limit
- Advantage
  - Timer backup, useful of weaning
- Disadvantages
  - Potential dyssynchrony
- Initial setting
  - FiO_2: 100%, V_T = 10-15 ml/kg, f = 12-15/min, PEEP = 0-5 cmH_2O
  - Inspiratory flow =60 L/min

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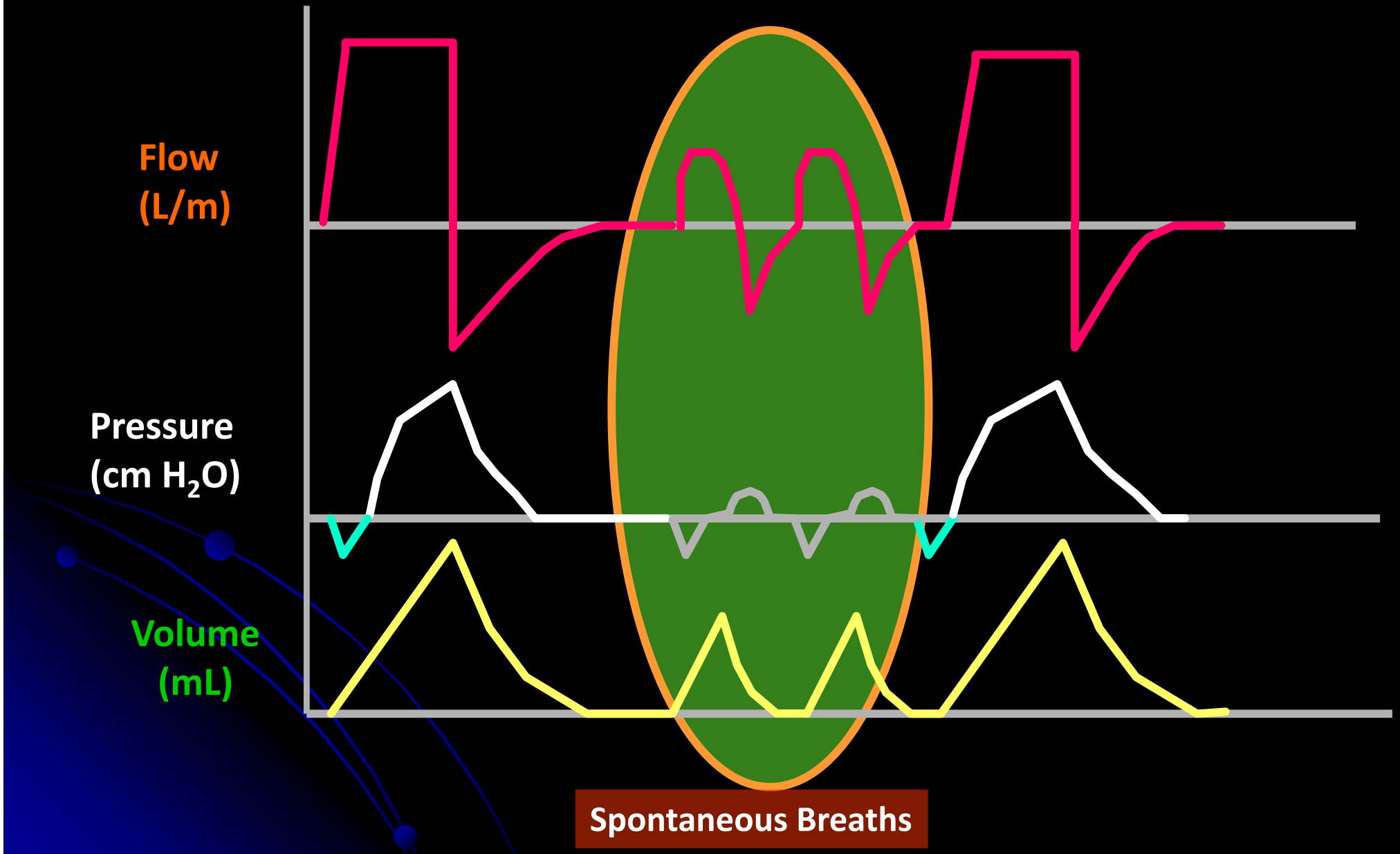
SIMV (volume-targeted ventilation)



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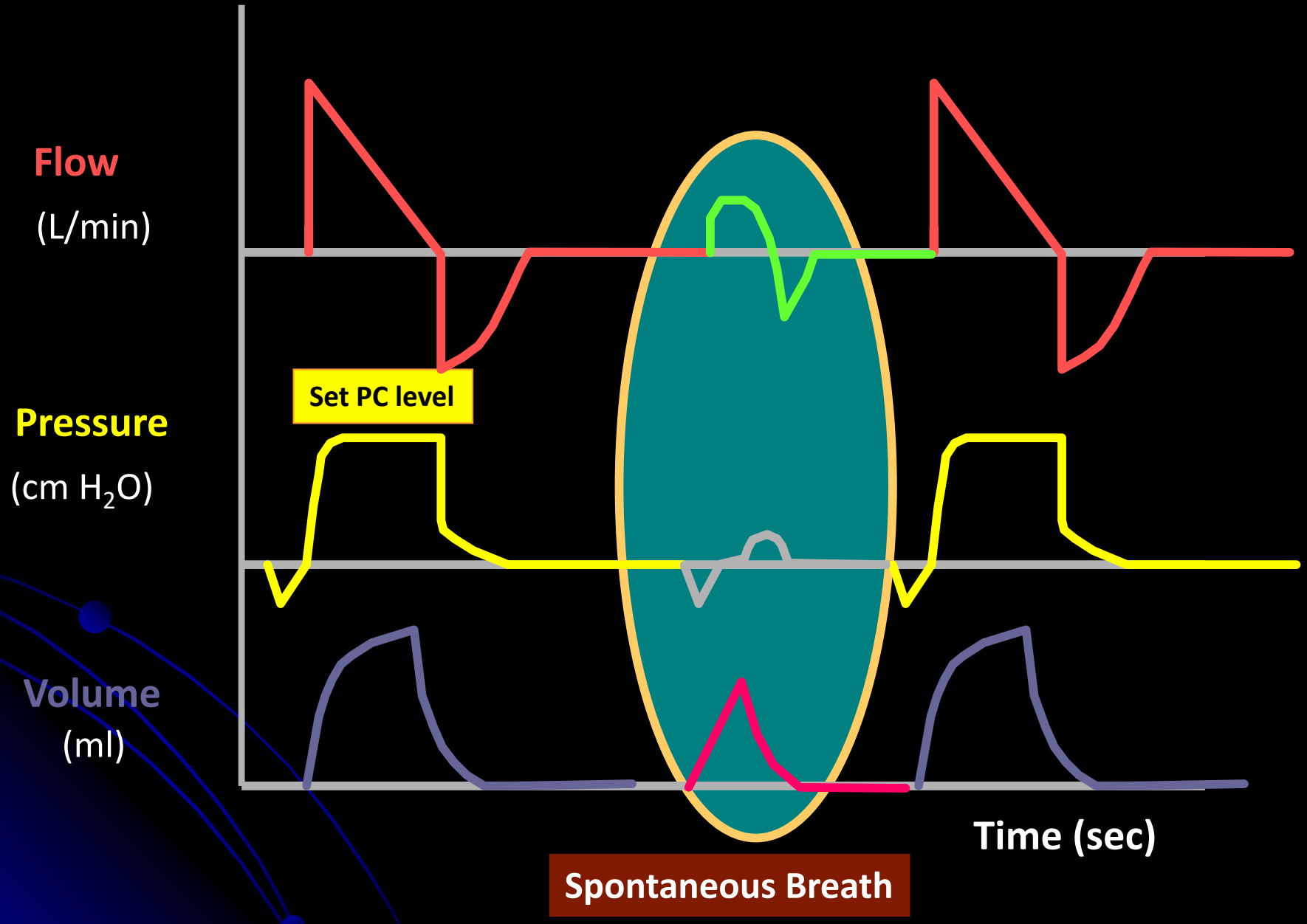
PSIMV (pressure-targeted ventilation)



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Pressure Support (PS)

- Independent variable (set by user)
  - FiO_2, tidal volume, PEEP, inspiratory pressure level, pressure limit
- Dependent variables
  - Same as for PCV +I/E ratio
- Trigger/cycle limit
  - Inspiratory flow, pressure limit
- Advantage
  - assures synchrony, good for weaning
- Disadvantages
  - No timer backup
- Initial setting
  - FiO_2: 50-100%, V_T =10-15 ml/kg, f = 12-15/min, PEEP = 0-5 cmH_2O
  - PS =10-30 cmH_2O

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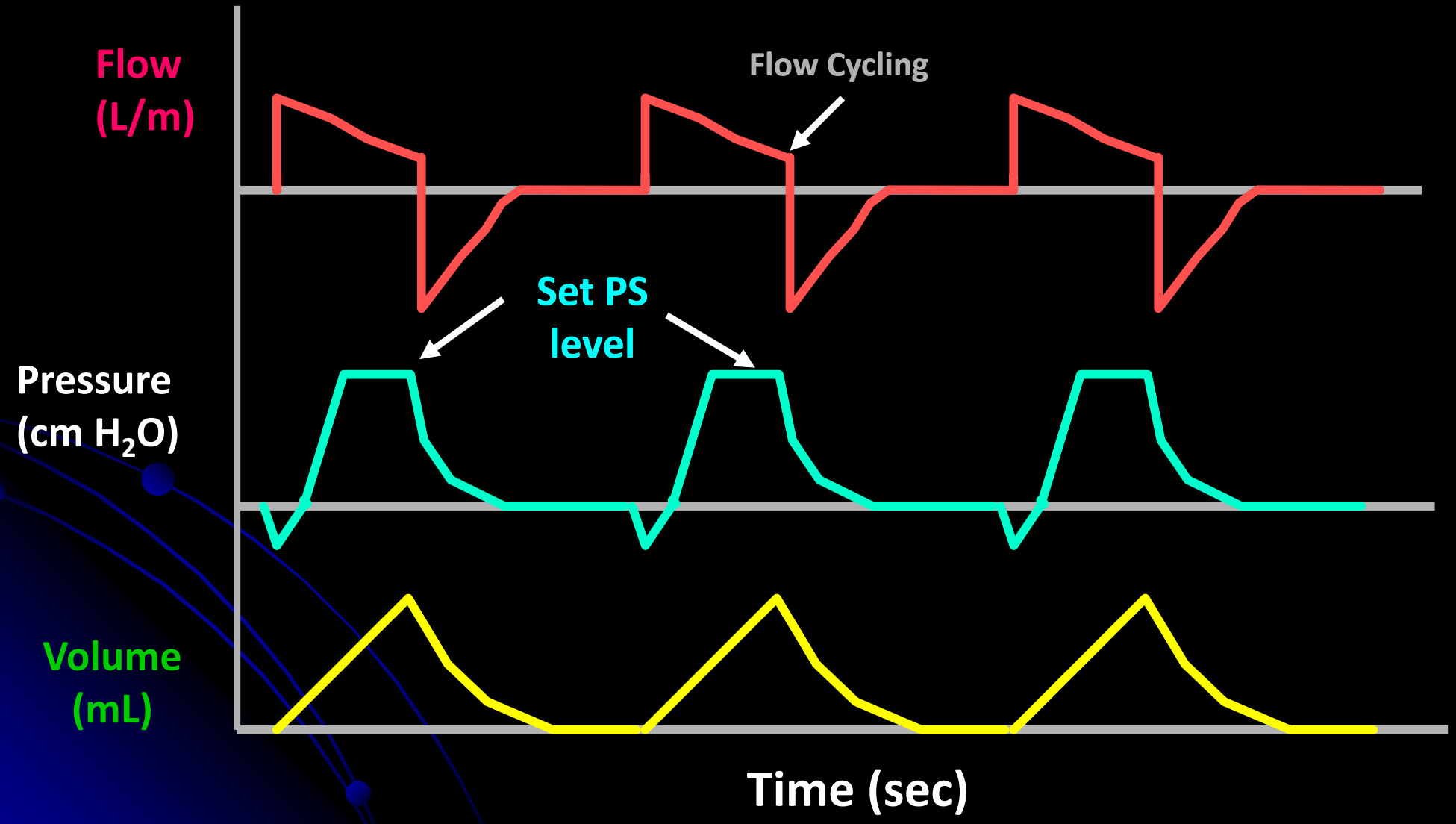
Pressure Support (PS)

Patient Triggered, Flow Cycled, Pressure limited Mode



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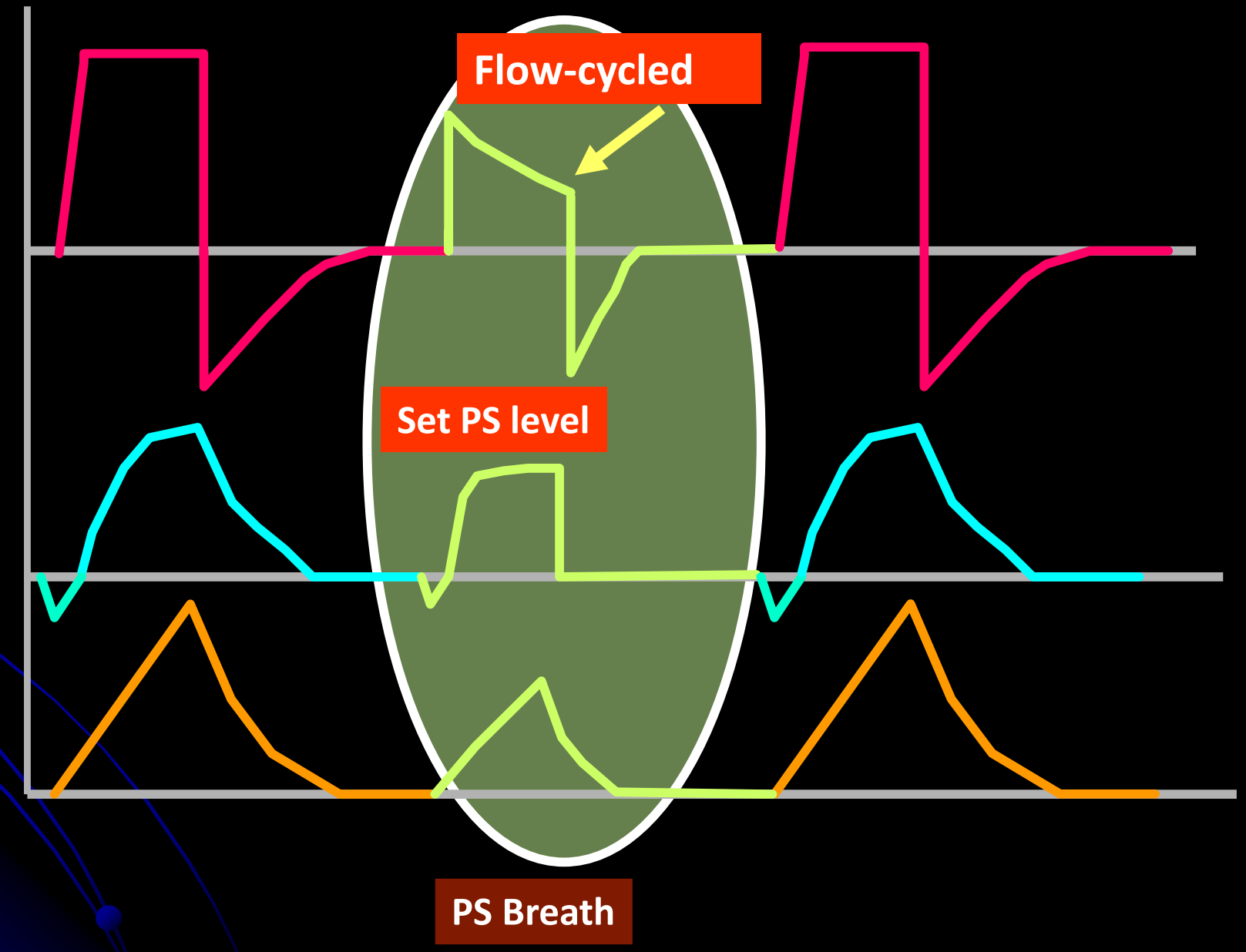
SIMV+PS (volume-targeted ventilation)



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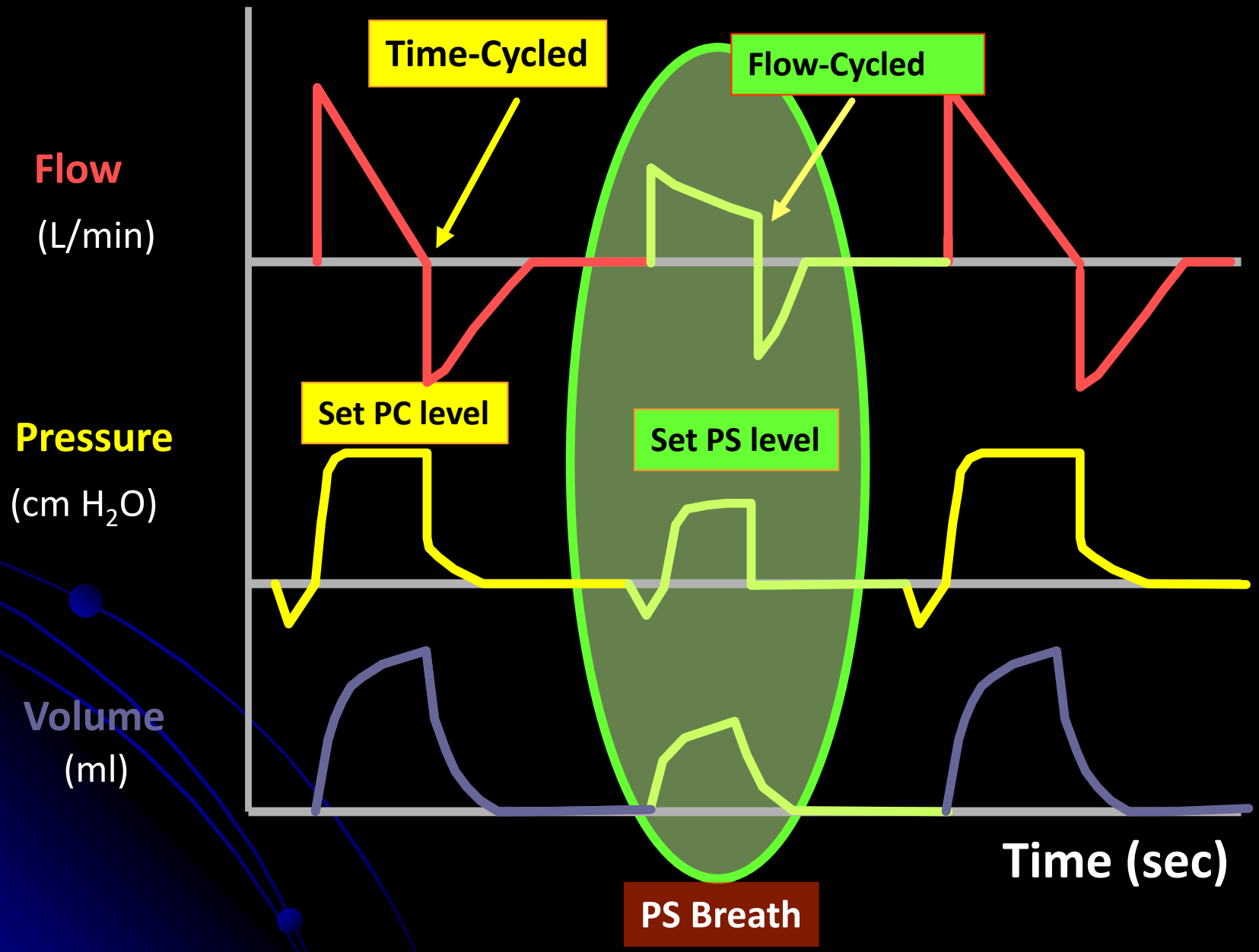
PSIMV + PS (pressure-targeted ventilation)



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Continuous Positive Airway Pressure (CPAP)

- Independent variable (set by user)
  - FiO_2, level of CPAP
- Dependent variables
  - Tidal volume, rate, flow pattern, PaO_2, $PaCO_2$, mean airway pressure, I/E ratio
- Trigger/cycle limit
  - No trigger, pressure limit
- Advantage
  - Allow assessment of spontaneous function, helps prevents atelectasis
- Disadvantages
  - No backup
- Initial setting
  - FiO_2: 50-100%, CPAP = 5-15 cmH_2O

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Outline

- Ventilator Need (Indications)
- Ventilator Operation
- Common Modes of Ventilation and Initial Settings
- **Specific Disease Consideration**
- Assessment and Trouble-Shooting

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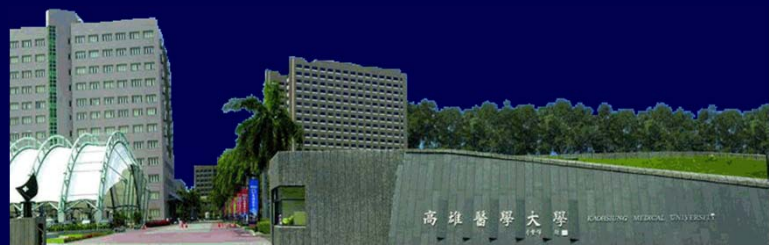

ARDS

Setting	Recommendations
Mode	SIMV or A/C in most acute stages; PS in early stages and during recovery
Rate	12-20 /min; avoid auto-PEEP
Volume/pressure target	Pressure or Volume
Tidal volume	4-8 mL/kg and plateau pressure ≦35 cmH_2O
Inspiratory time	Extend to achieve oxygenation target, limited by development of auto-PEEP
PEEP	≧ 10 cmH_2O
FiO_2	As needed to achieve PaO_2 target, ≦ 0.80
Flow waveform	Decelerating
Mean airway pressure	Lowest level to achieve PO_2 target (> 20-25 cmH_2O may be required)

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[Hess DR, Kacmarek R. 2002. Essentials of Mechanical Ventilation, 2nd ed.]

ARDS

Setting	Recommendations
Mode	A/C (CMV) in most acute stages; PS in early stages and during recovery
Rate	20-40 /min; avoid auto-PEEP
Volume/pressure target	Pressure or Volume
Tidal volume	4-8 mL/kg and plateau pressure ≤ 30 cmH_2O
Inspiratory time	Ensure synchrony in patient-triggered ventilation (0.5-0.8 sec), may incorporate a short end-inspiratory pause in passive ventilation
PEEP	10-20 cmH_2O; lowest level to achieve SpO_2/PaO_2 target
FiO_2	As needed to achieve SpO_2/PaO_2 target

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COPD

Setting	Recommendations
Mode	SIMV or A/C
Rate	6-8 /min; avoid auto-PEEP
Volume/pressure target	Pressure
Tidal volume	8-12 mL/kg and plateau pressure <30 cmH_2O
Inspiratory time	0.8-1.2 sec (peak flow ≧ 60L/min with volume ventilation)
PEEP	≧ 5 cmH_2O to balance auto-PEEP
FiO_2	Usually ≦ 0.50
Flow waveform	Decelerating

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COPD

Setting	Recommendations
Mode	A/C (CMV)
Rate	8-15 /min
Volume/pressure target	Pressure or volume
Tidal volume	6-8 mL/kg provided plateau pressure ≤ 30 cmH_2O
Inspiratory time	0.6-1.0 sec
PEEP	5 cmH_2O or as necessary to counterbalance auto-PEEP
FiO_2	Usually ≤ 0.50

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Severe Acute Asthma

Setting	Recommendations
Mode	Pharmacologically controlled full ventilatory support; SIMV or A/C
Rate	≦ 8 /min; allow permissive hypercapnia (pH > 7.10-7.20)
Volume/pressure target	Pressure (usually preferred for sever asthma) Volume
Tidal volume	≦10 mL/kg and plateau pressure ≦35 cmH_2O
Inspiratory time	≦ 1-1.5 sec (peak flow ≧ 60L/min with volume ventilation); avoid auto-PEEP
PEEP	During spontaneous breathing, increase to match auto-PEEP; During controlled ventilation, increase to 80% of auto-PEEP with caution
FiO_2	1.0 or sufficient to maintain PaO_2 ≧ 60mmHg
Flow waveform	Decelerating

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Severe Acute Asthma

Setting	Recommendations
Mode	A/C (CMV)
Rate	8-20 /min; allow permissive hypercapnia
Volume/pressure target	Pressure or volume; volume necessary for severe asthma
Tidal volume	4-6 mL/kg and plateau pressure ≤ 30 cmH_2O
Inspiratory time	1-1.5 sec; avoid auto-PEEP
PEEP	Use of PEEP is controversial; may attempt to counterbalance auto-PEEP but frequently this does not help
FiO_2	Sufficient to maintain PaO_2 55-80 mmHg and SpO_2 88%-95%

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Head Injury

Setting	Recommendations
Mode	SIMV or A/C
Rate	10-15 /min (15-20 /min if necessary to control ICP provided that auto-PEEP is not present)
Volume/pressure target	Volume; Pressure if there is high airway pressure due to low lung compliance (e.g., neurogenic pulmonary edema)
Tidal volume	12-15 mL/kg; plateau pressure ≦35cmH_2O
Inspiratory time	1 sec
PEEP	5 cmH_2O provided that PEEP does not increase ICP
FiO_2	1.0
Flow waveform	Decelerating

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Head Injury

Setting	Recommendations
Mode	CMV (A/C)
Rate	15-25 /min
Volume/pressure target	Volume or pressure
Tidal volume	6-8 mL/kg provided that plateau pressure ≤ 30cmH_2O
Inspiratory time	1 sec
PEEP	5 cmH_2O provided that PEEP does not increase ICP
FiO_2	1.0

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Lung-protective Ventilatory Strategy

- If possible, the lower the better!

http://www.kanezo.com.tw/products_detail.php?sn=78

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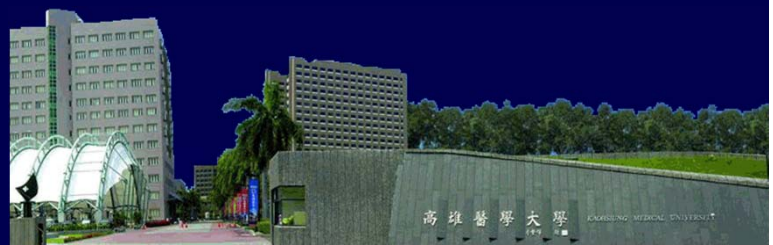

Causes of sudden respiratory distress in MV P’ts

- **Patient-related**
  - Artificial airway problems
  - Pneumothorax
  - Bronchospasm
  - Secretions
  - Pulmonary edema
  - Pulmonary embolus
  - Dynamic hyperinflation
  - Abnormal respiratory drive
  - Alteration in body posture
  - Drug-induced problems
  - Anxiety
  - Patient-ventilator asynchrony
- **Ventilator-related**
  - System leak
  - Circuit malfunction or disconnection
  - Inadequate fractional inspired O_2 (FiO_2)
  - Inadequate ventilatory support
  - Inadequate trigger sensitivity
  - Improper inspiratory flow setting
  - Patient-ventilator asynchrony

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Trouble Shooting

- Remove the patient from the ventilator
- Initiate manual ventilation using a self-inflating resuscitation bag containing 100%
- Perform a rapid physical examination and assess monitored indices
- Check patency of the airway and pass a suction catheter
- If death appears imminent, consider and treat most likely causes: pneumothorax, airway obstruction
- Once the patient is stabilized, perform more detailed assessment and management → ABG is usually needed!

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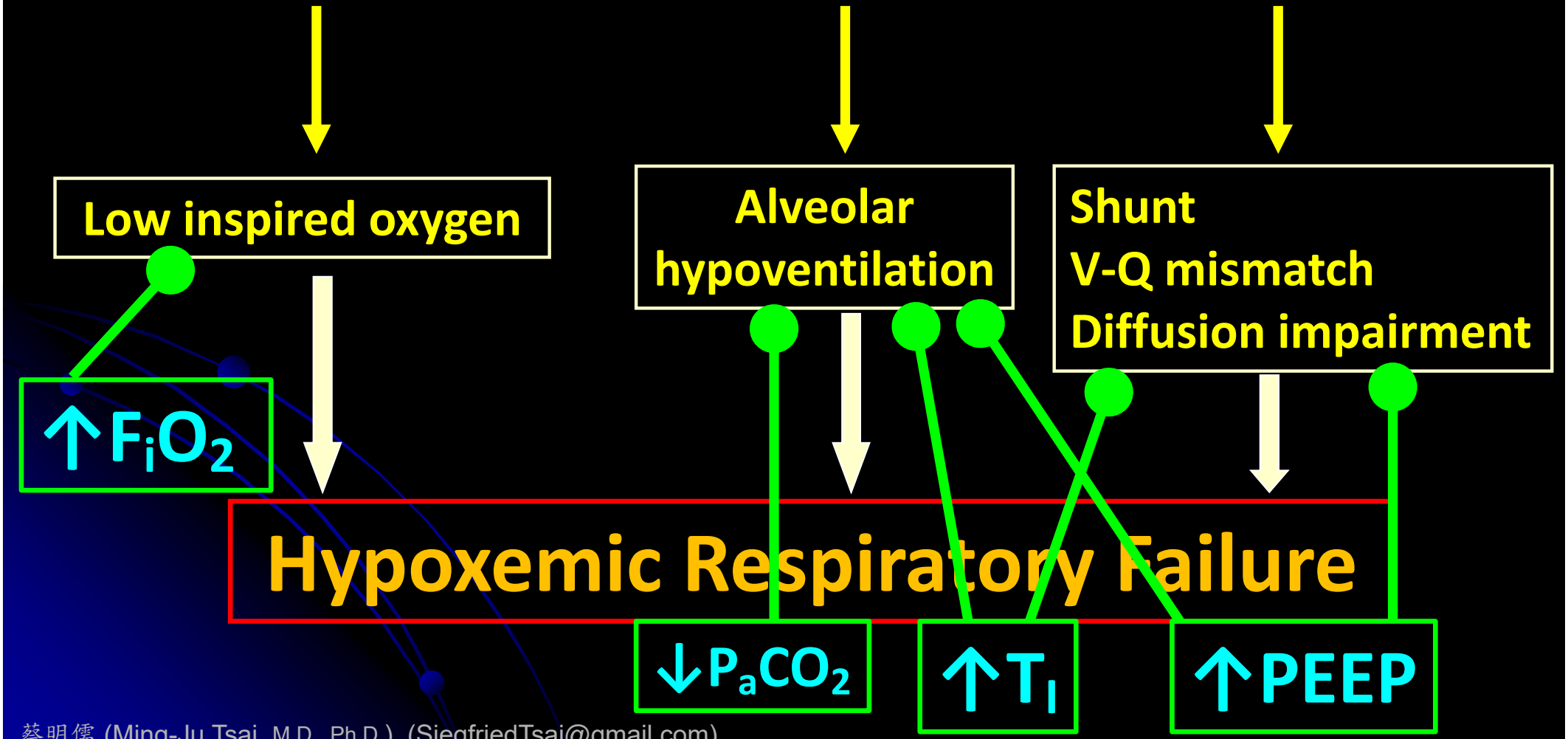
$P_AO_2 = P_iO_2 - P_ACO_2/R$

A-a gradient = $P_AO_2 - P_aO_2$

$$P_aO_2 = [\ F_iO_2\ (P_{ATM} - P_{H2O}) - P_aCO_2/R\ ] - [\text{A-a gradient}]$$



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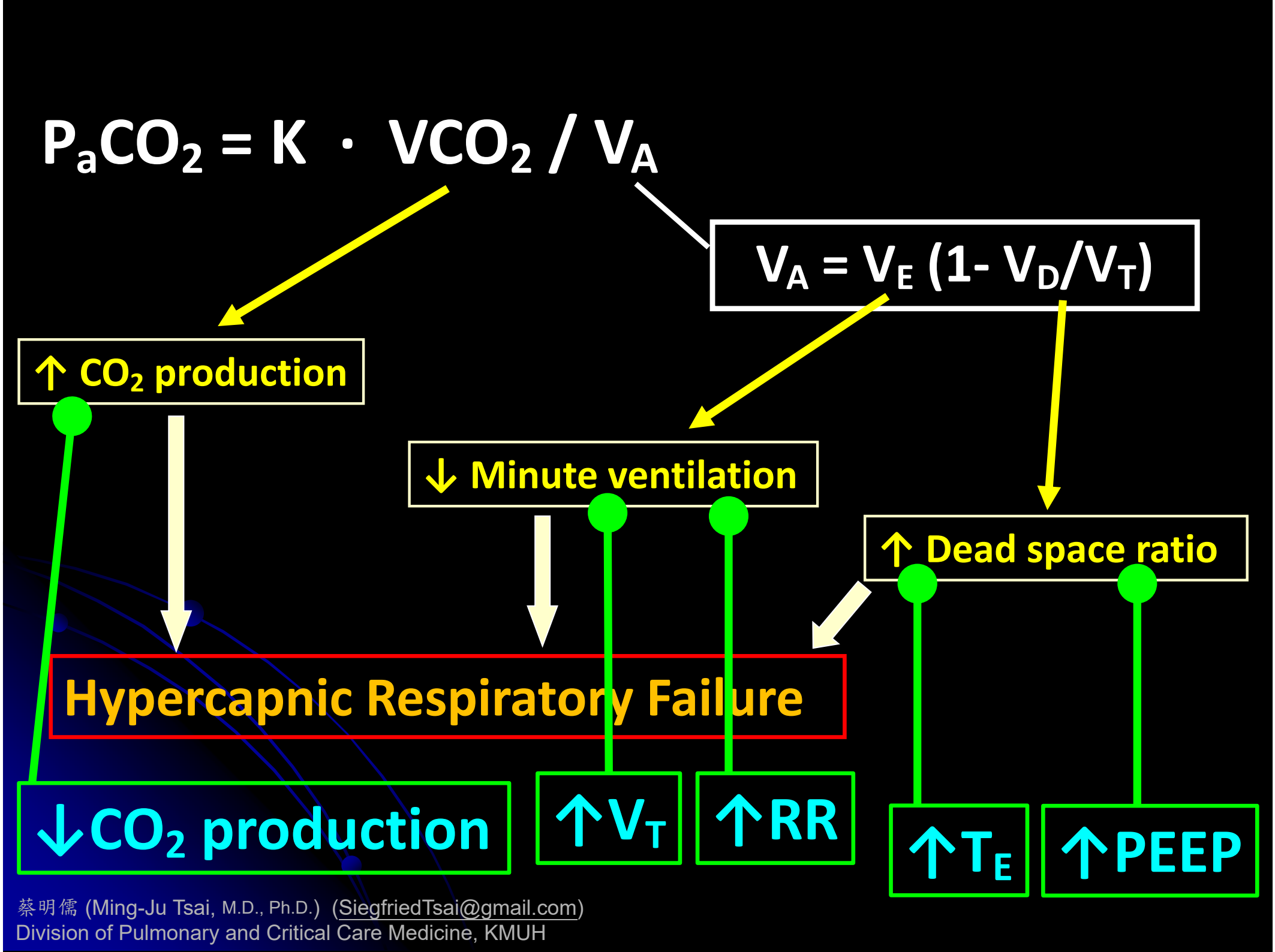

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Take-Home Message

- Major settings of MV:
  - Mode
    - CMV (A/C): VCV, PCV
    - SIMV: SIMV+PS, PSIMV+PS
    - PS
  - FiO_2
  - Minute volume (V_E) = Tidal volume (V_T) * Rate (RR, f)
  - PEEP (positive end-expiratory pressure)
  - I:E ratio (Inspiratory time (T_I), Expiratory time (T_E))
  - Trigger sensitivity
  - Alarms

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Thank you for your attention!
Danke schön für Ihre Beachtung!!
どうも ありがとう ございました！

敬請指教