



彰化基督教醫院  
CHANGHUA CHRISTIAN HOSPITAL

# Monitoring and Troubleshooting for patients with Mechanical Ventilation

 CHANGHUA CHRISTIAN HOSPITAL

林楷煌 醫師 20200726

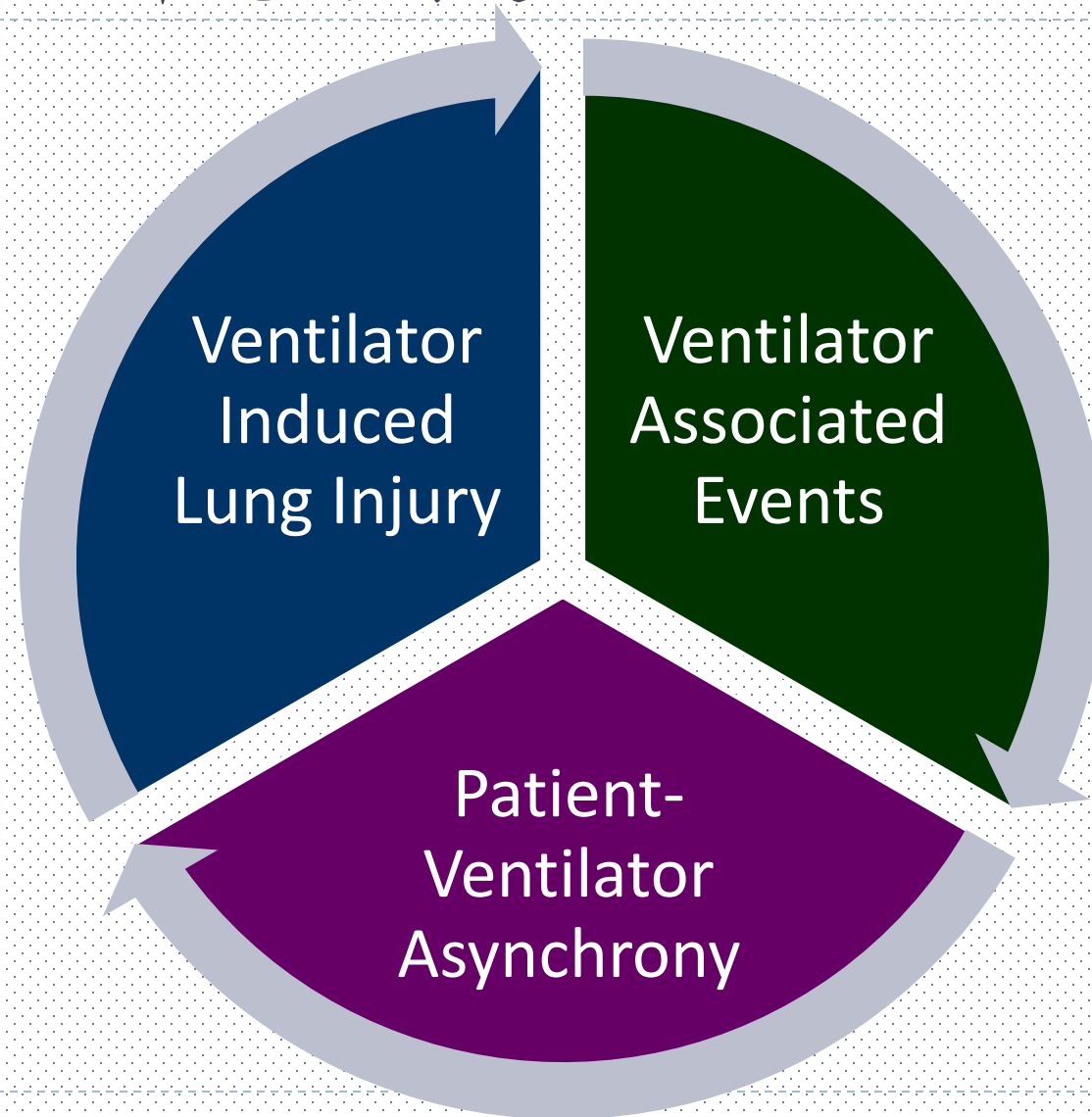
彰化基督教醫院 內科部重症醫學科

(急診重症醫學部重症內科 20200101)

# Goal of Mechanical Ventilation

- Type 1(**Hypoxemic/Oxygenation**) respiratory failure
- Type 2(**Hypercapnic/Ventilatory**) respiratory failure
- Type 3(**Perioperative**) respiratory failure
- Type 4(**Shock**) respiratory failure
- Improve gas exchange and oxygenation
- Reduce work of breathing (WOB).
- Improve gas exchange and oxygenation
- Reduce work of breathing

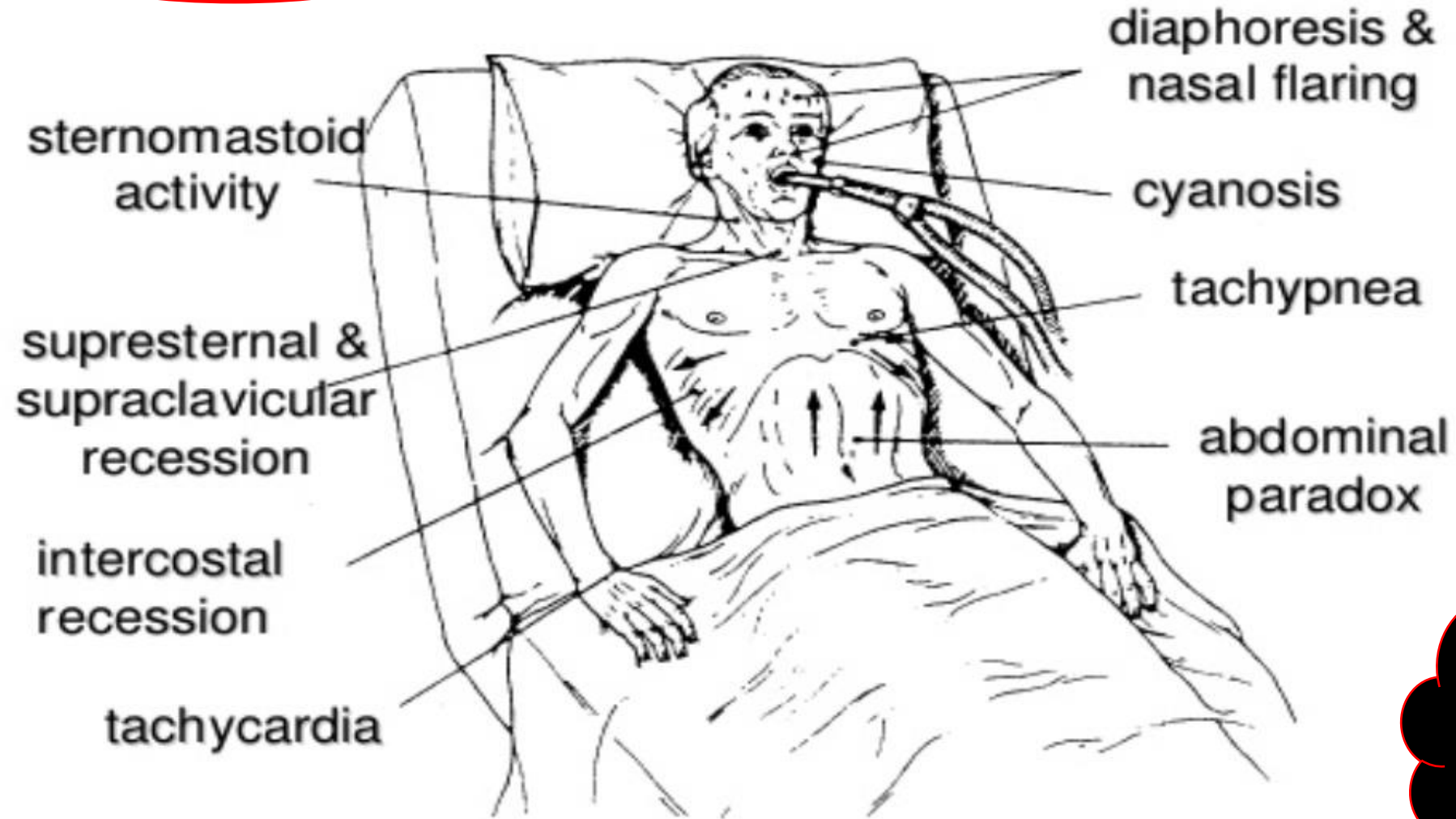
# 臨床上使用呼吸器常見的問題



# Asynchrony (Dyssynchrony)

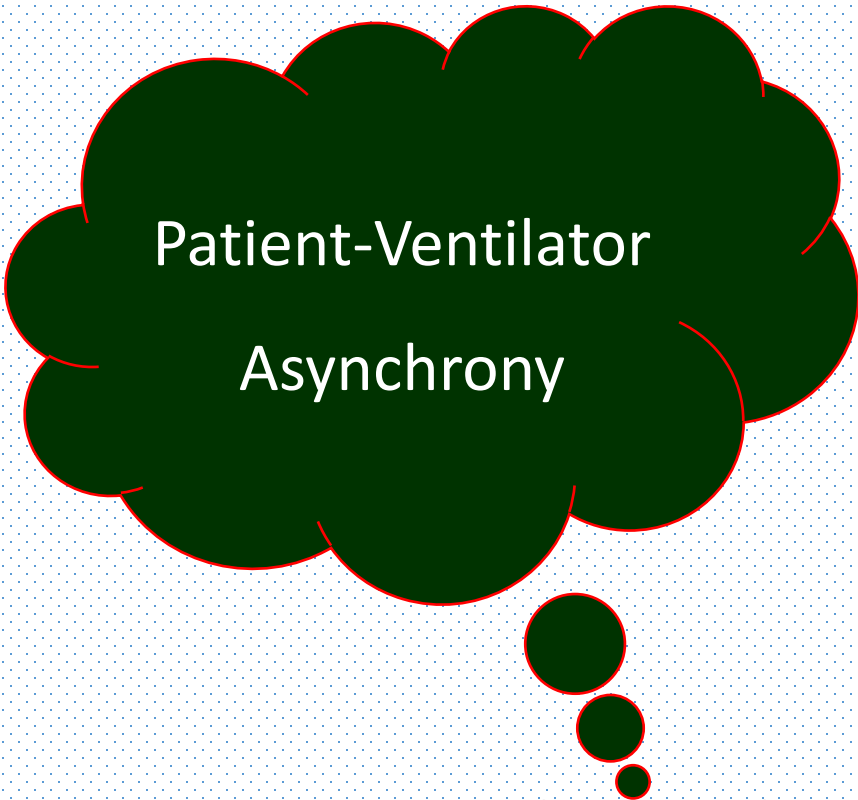
- A **mismatch** between the **inspiratory** and **expiratory** phase of patient and ventilator ( regarding **Time/ Flow/ Volume/ Pressure** demands )
- Ventilator failed to provide optimal assistance.
- Frequent issue and Associated with worse outcomes
  - Prolonged MV, Prolonged ICU & hospital stays, Increased M & M

# ***Dissynchrony between Patient & Ventilator***



*Tobin MJ. Principles and Practice of MV. 1994.*

Gross

A green thought bubble with a red outline, containing the text "Patient-Ventilator Asynchrony".

Patient-Ventilator  
Asynchrony

A dark blue thought bubble with a red outline, containing the text "Improve Patient-Ventilator Synchrony".

Improve  
Patient-Ventilator  
Synchrony

**Monitoring and Troubleshooting**  
for patients with MV

# Contents

- Incidence
- Cause
- Classification
- Management
  - How to find and treat
- Future (recent advances)
  - How to prevent

# Patient-ventilator Asynchrony during Assisted Mechanical Ventilation

Arnaud W T

erent Brochard

MV: Evita 2 & 4/PB 840/Vela/T-Bird/8400

Incidence(AI>10%): 15/62 (24%)

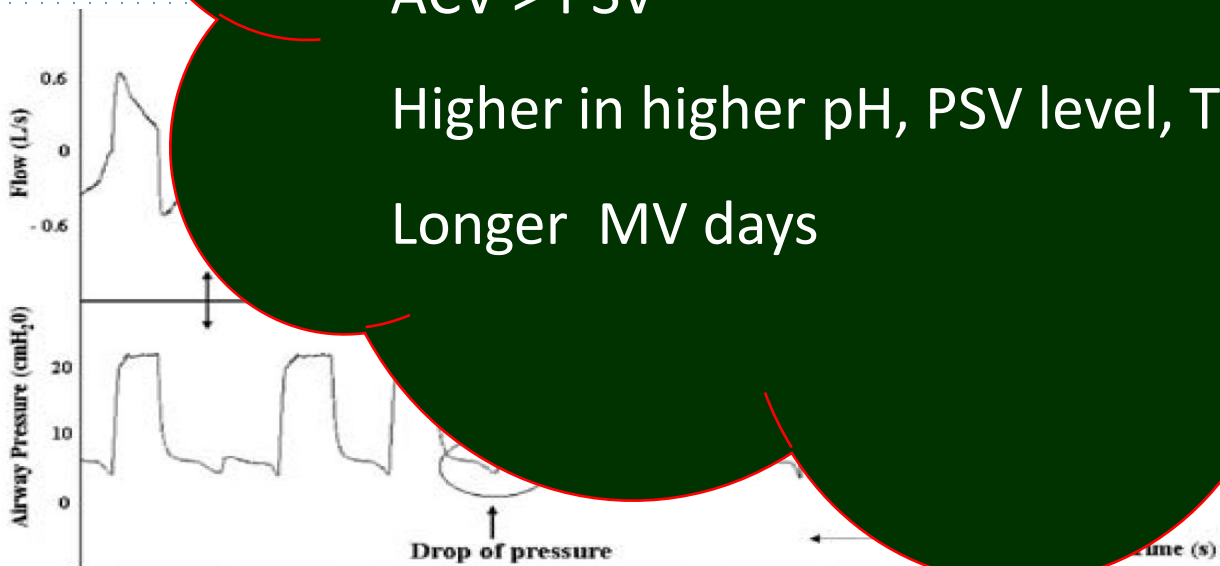
Main patterns: Ineffective triggering (85%)

Double triggering(13%)

ACV > PSV

Higher in higher pH, PSV level, TV

Longer MV days



# Patient-Ventilator Asynchrony(PVA)

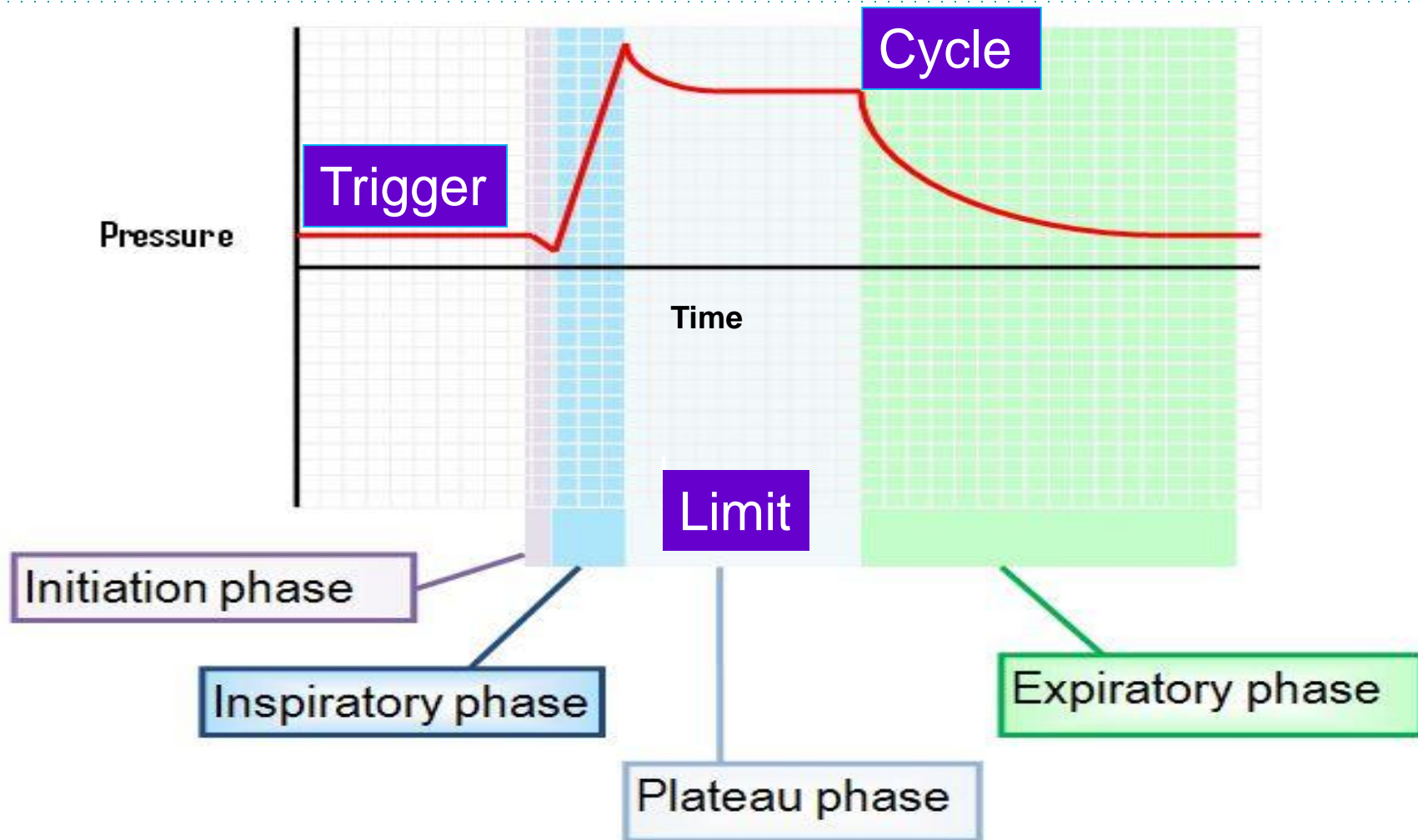
Incidence: > 10% of total breaths

	No. of participants	Condition	Mode	% of patients with asynchrony index* > 10
<b>Chao</b> <i>CHEST 1997; 112:1592-99</i>	200	PMV weaning center	VCV,PSV	10 ( trigger asynchrony)
Thille AW, <i>ICM. 2006;32(10):1515-1522.</i>	62	ICU MV>24H	ACV, PSV	24
Robinson BR, <i>RC. 2013;58(11):1847-1855.</i>	35	TRAUMA	SIMV, PSV	25.7
Blanch L, <i>ICM 2015;41(4):633-641.</i>	50	ICU MV>24H	PCV, VCV, PSV	12

# Contents

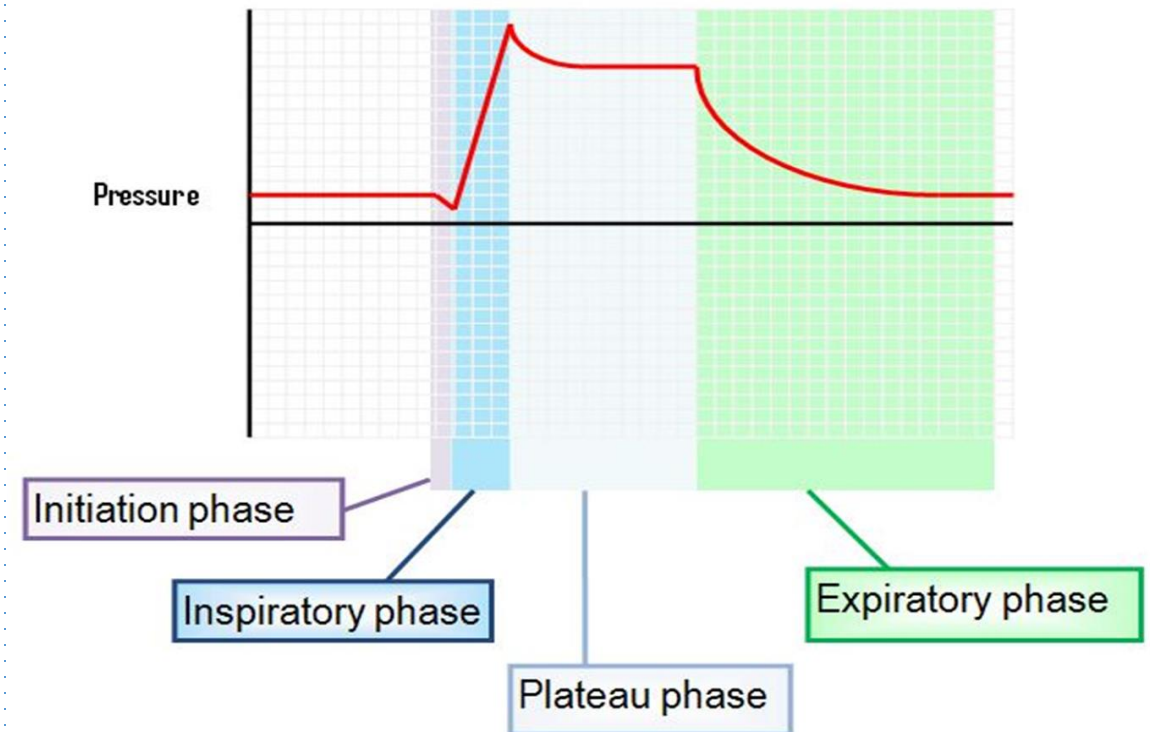
- Incidence
- **Cause**
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# Phases & Waveform of Mechanical breath



# Patient-Ventilator Asynchrony

- Resulting from problems with:
  - Timing of inspiration
  - Adequate inspiratory flow for demand
  - Duration of inspiration
  - Timing of the switch to expiration



# Causes of Patient-Ventilator Asynchronies

## Patient factors

- Respiratory drive  
  inspiration
- Ventilatory requirements  
  how much flow & volume required
- Respiratory rhythm (I:E ratio)



## Ventilator factors

- Inspiratory trigger  
  Flow / Volume / Pressure
- Delivery mechanism  
  Flow / Volume / Pressure
- Cycling criteria  
  Stops inspiration, Allows exhalation



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**Table 3—A Classification of Patient-Ventilator Asynchrony**

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Asynchrony
Phase asynchrony
TA
Trigger and posttrigger delay
Autocycling
Double triggering
Expiratory asynchrony (inappropriate cycling-off algorithm for PS mode, volume setting for volume-cycled mode, or I-time setting for time-cycled mode)
Flow asynchrony
Inadequate (“flow starvation”) or excessive inspiratory flow rate
Inadequate or excessive flow acceleration (“attack rate,” “rise time”)
Inappropriate inspiratory flow profile

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# Classifications of patient-ventilator asynchronies

- Phase classification

- Inspiratory : delayed triggering, ineffective efforts, auto-triggering
- Expiratory : late and early cycling, double-triggering.

- Etiology classification

- Low respiratory drive  $\pm$  too much ventilator assistance:
  - ineffective efforts, delayed cycling, auto-triggering, reverse triggering.
- High respiratory drive and low ventilator support:
  - early cycling, double-triggering.

# Causes of In-Phase Asynchronies

Ineffective triggering  
 Inappropriate triggering  
 Auto-triggering

## Patient factors

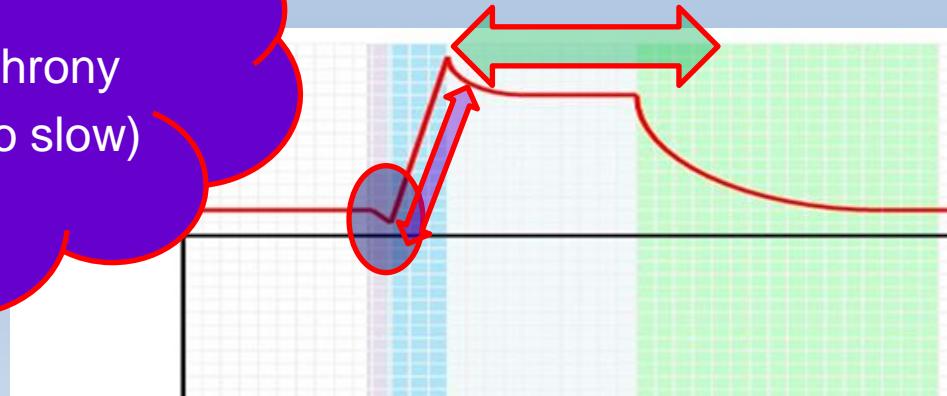
- Respiratory drive  
 inspiration
- Ventilatory requirements  
 how much flow and volume required
- Respiratory rhythm (I:E ratio)

## Ventilator factors

- Inspiratory trigger  
 flow/volume
- Delivery mechanism  
 flow/volume/pressure
- Cycling criteria  
 stops inspiration, allows exhalation

Exhalation (Cycle)  
 dysynchrony  
 (too early or too late)

Flow dyssynchrony  
 (too fast or too slow)



# Contents

- Incidence
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# How to improve patient-ventilator synchrony

- Ventilator factor
  - Waveform analysis
  - Optimization of ventilator settings
- Patient factor
  - Solve patient pathological condition
    - Bronchospasm, ARDS Protocol, Prone Position, Pneumothorax , PADIS problem etc.

Needs expertise

No automated analysis from ventilators

May miss some

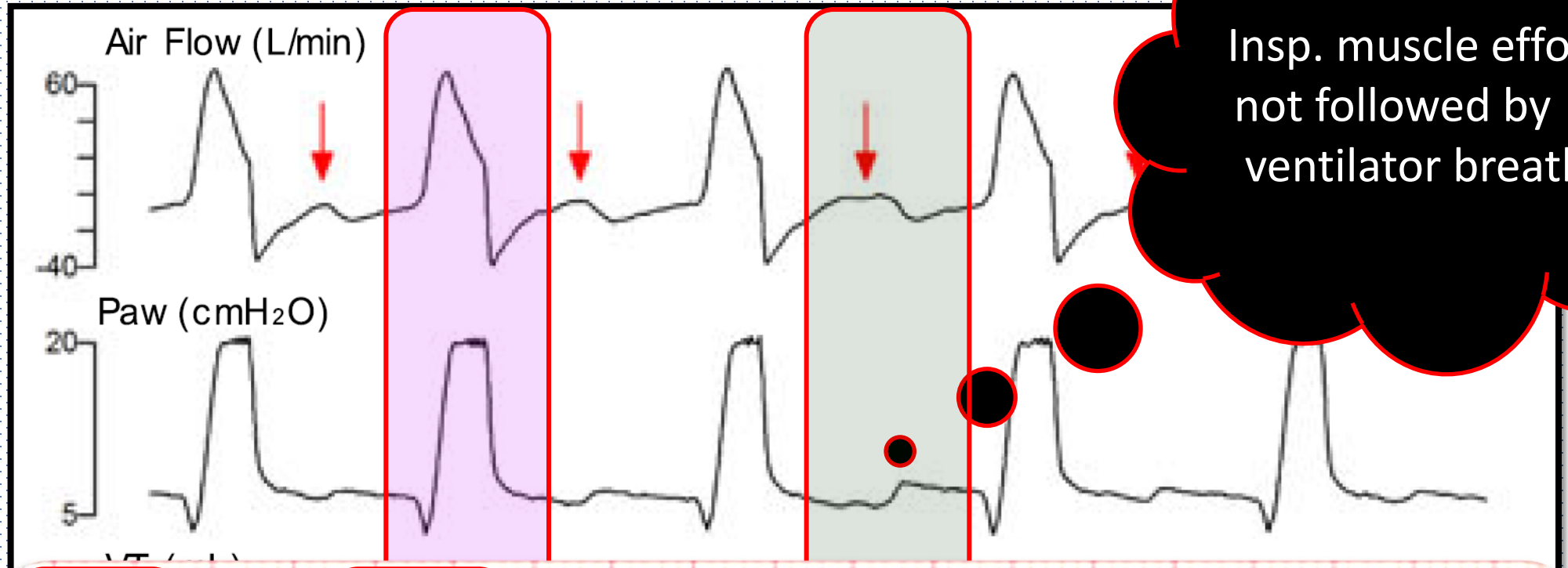
# Common types of Patient-Ventilator Asynchrony

- Ineffective triggering
- Inappropriate triggering (patient insp. , the ventilator cycles to exp.)
- Auto-triggering (important to distinguish from ineffective triggering)
- Flow dyssynchrony (too fast or too slow)
- Exhalation dyssynchrony (too early or too late)

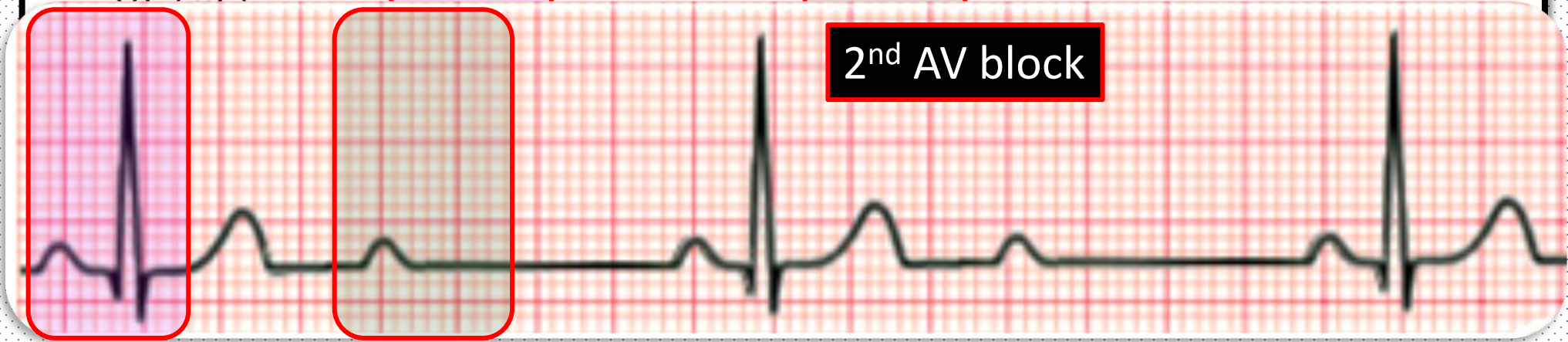
# Patient-Ventilator Asynchrony (I)

- **Ineffective triggering** (Insp. muscle effort not followed by a ventilator breath)
  - High PEEPi (auto-PEEP, must generate enough effort to overcome )
  - Weakness
  - Incorrect ventilator settings
  - Ventilator dysfunction

# Ineffective trigger



Insp. muscle effort not followed by a ventilator breath



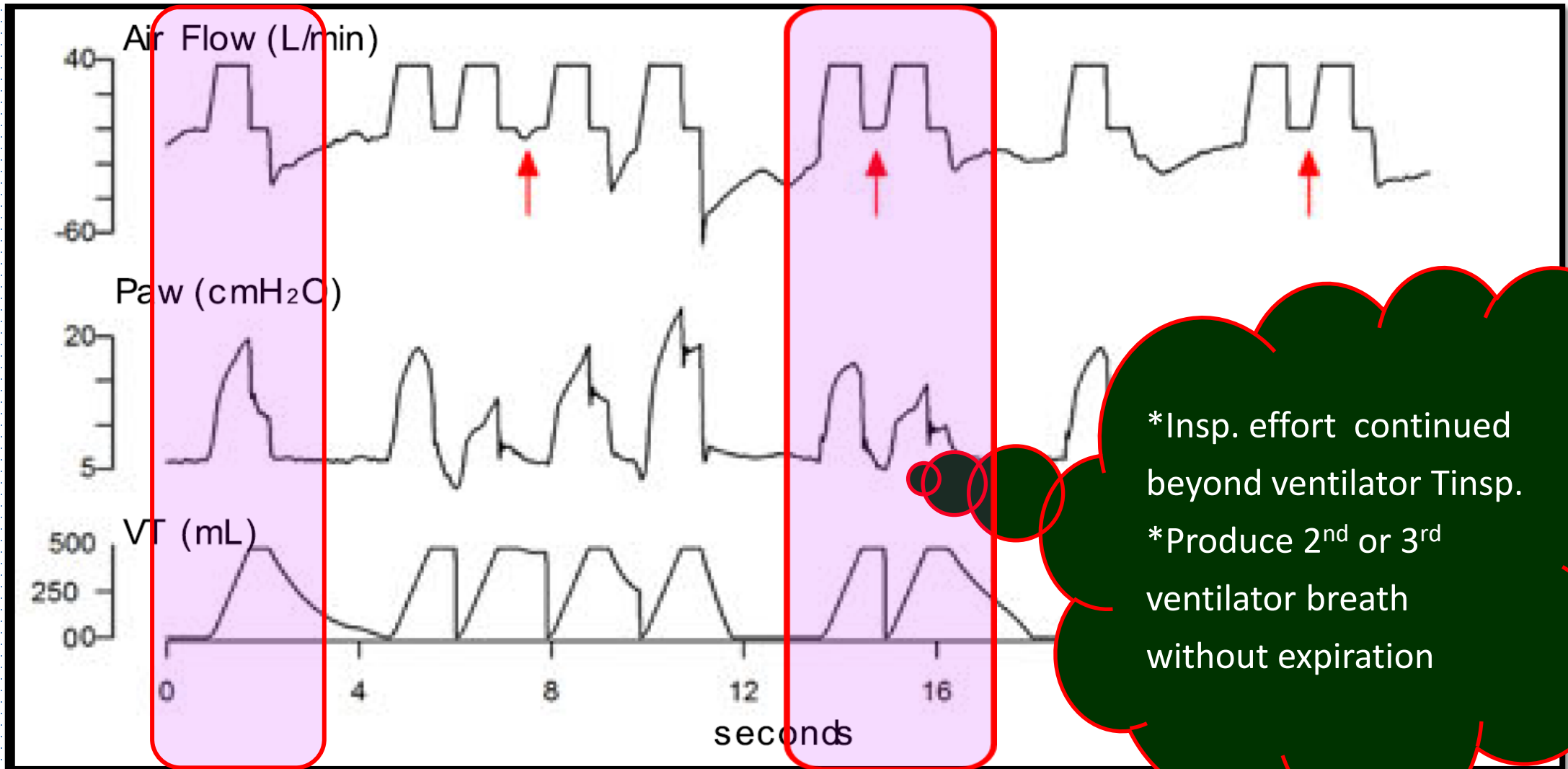
# Management of Ineffective Triggering

- PEEPi :
  - apply increased externally applied PEEP
  - decrease tidal volume and respiratory rate
  - increase expiratory time
  - bronchodilators
- Weakness:
  - nutrition/ reduce sedation/ physiotherapy
- Adjust trigger sensitivity threshold

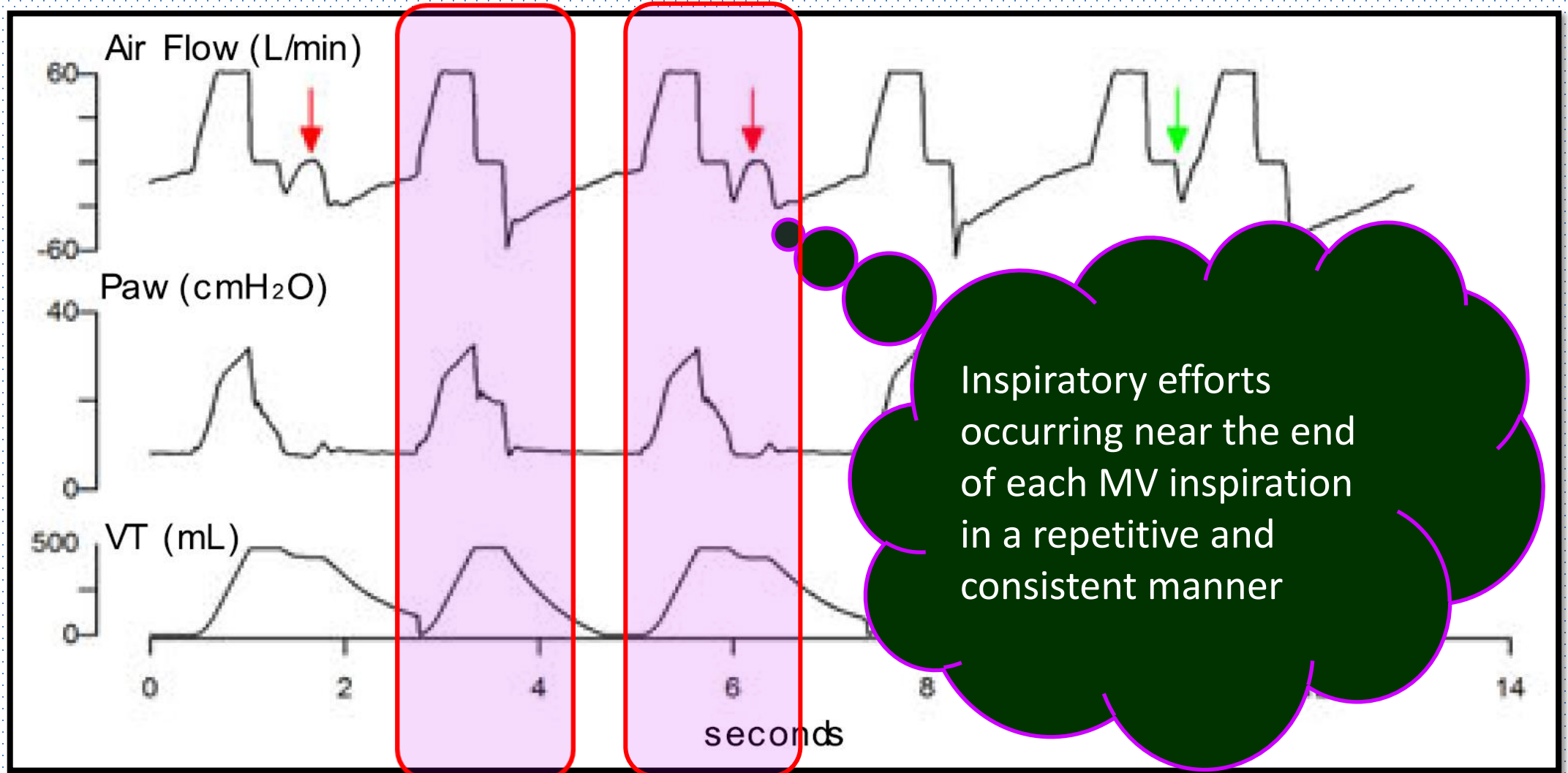
# Patient-Ventilator Asynchrony (II)

- Inappropriate triggering (patient inspires, ventilator expiration)
  - Double triggering
    - Patient trigger 1, MV delivering 2
    - Patient neural inspiratory time > the ventilator inspiratory time.
  - Reverse triggering
    - Reflex mechanisms, retriggered by mechanical insufflation in a controlled breath

# Double trigger



# Reverse triggering



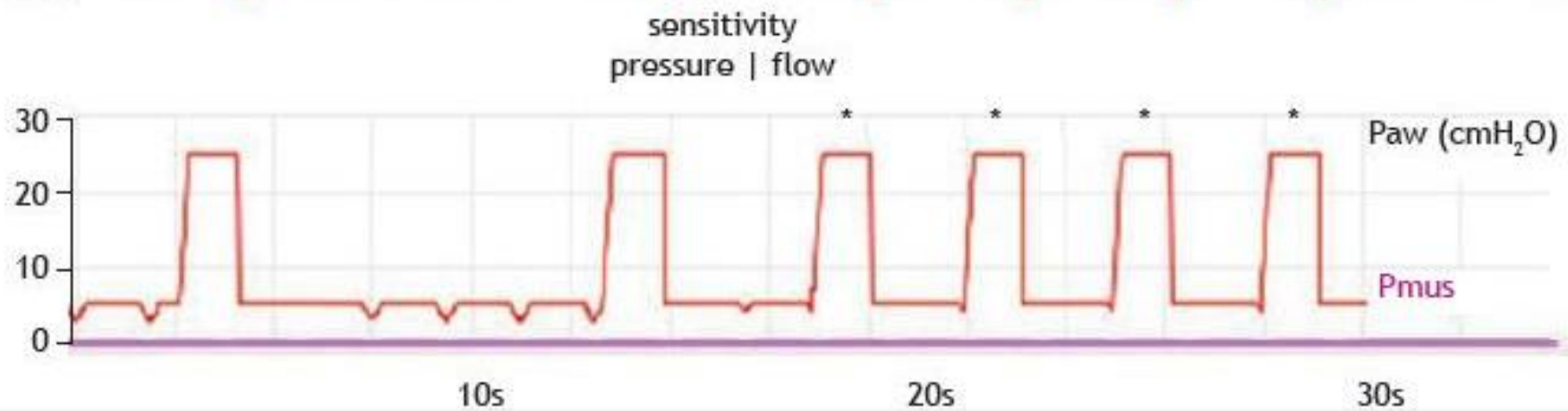
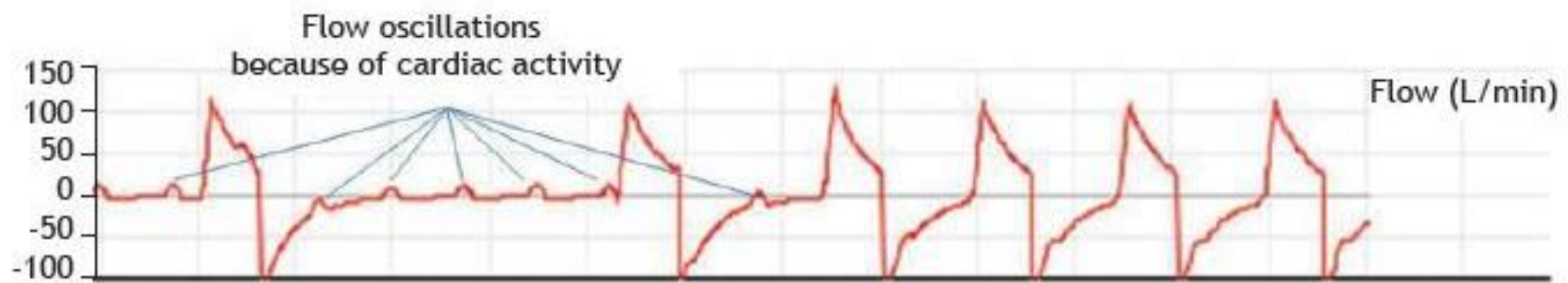
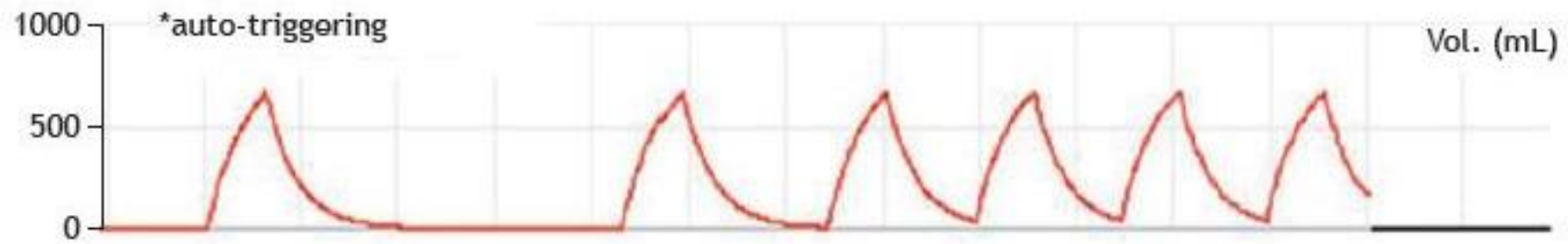
# Patient-Ventilator Asynchrony (II)

- Inappropriate triggering (patient inspires, ventilator expiration)
  - Inspiratory time too short
  - Inspiratory flow rate too low
  - Set tidal volume low
  - Coughing and hiccups
- The main therapeutic strategy
  - increasing inspiratory time (in VCV and PCV)
  - in PSV mode, increasing inspiratory time by decreasing the cycling percentage of peak flow.

# Patient-Ventilator Asynchrony (III)

- Auto-triggering
  - the ventilator improperly recognizes a flow or pressure variation in the circuit as being patient spontaneous respiratory muscle effort.
  - the ventilator sensitivity system is “tricked” by artifacts
    - **leaks** with depressurization of the circuit
    - the presence of **condensate** in the circuit
    - **cardiac oscillations** due to systolic ejection

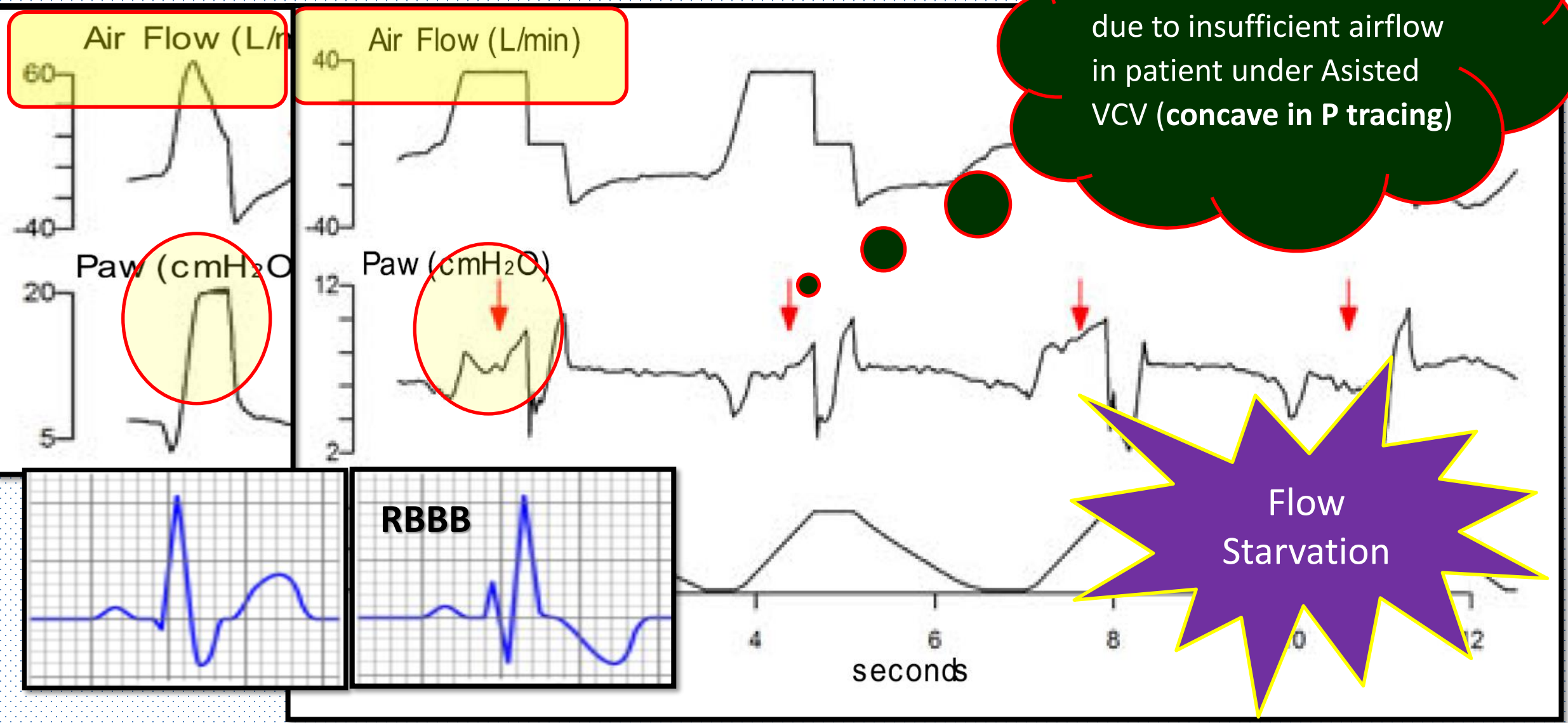


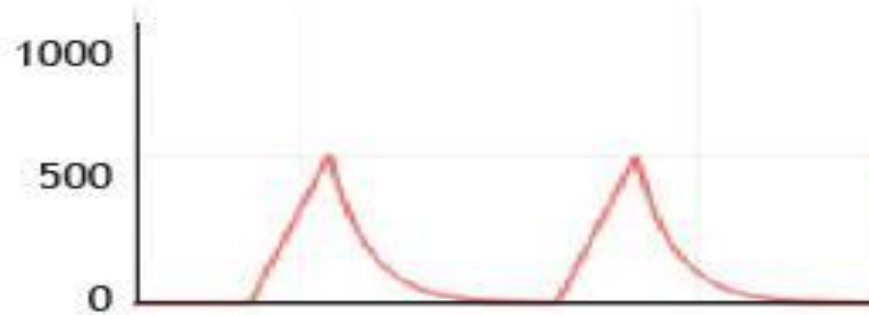


# Patient-Ventilator Asynchrony (IV)

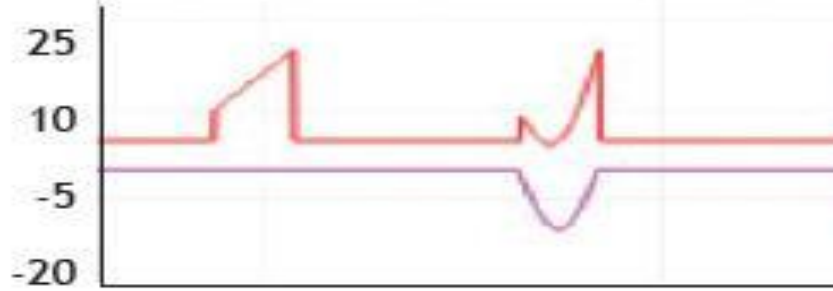
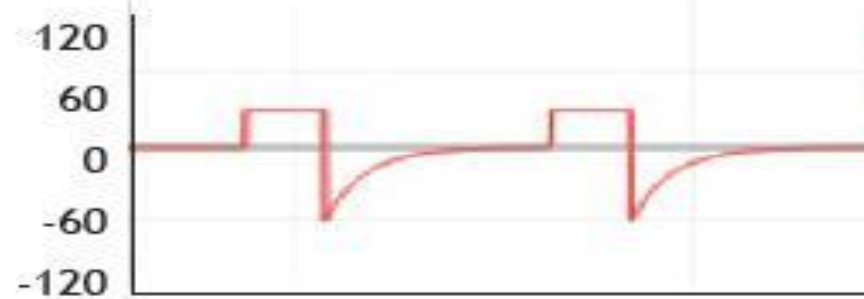
- Flow Dyssynchrony (Most Too Slow)
  - **Strong Inspiratory Effort Due To Insufficient Airflow**
  - In Patient Under Asisted VCV
  - Concave In P Tracing

# Inspiratory airflow dyssynchrony

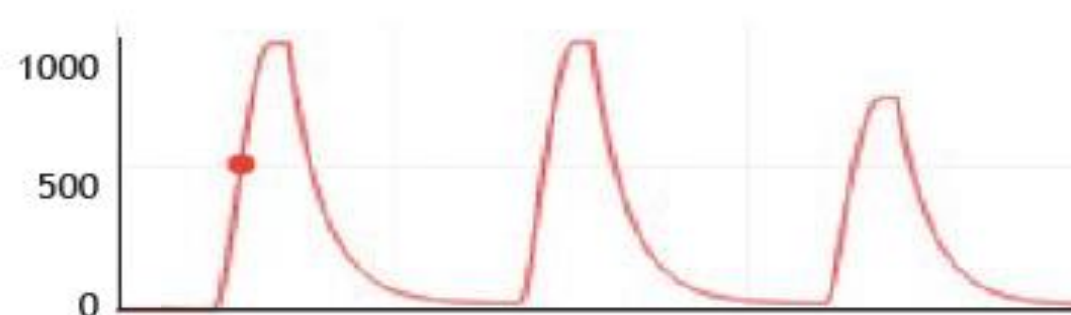




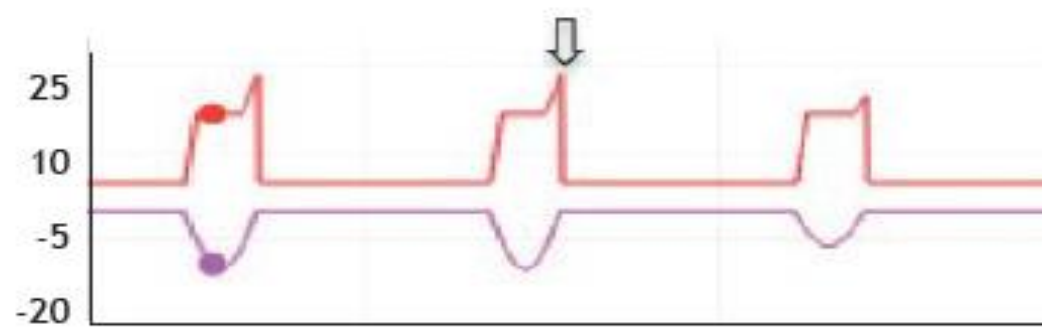
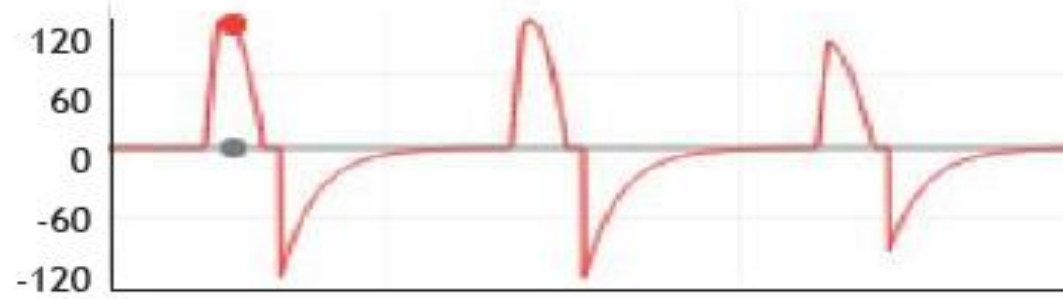
VCV



10s



PCV



20s

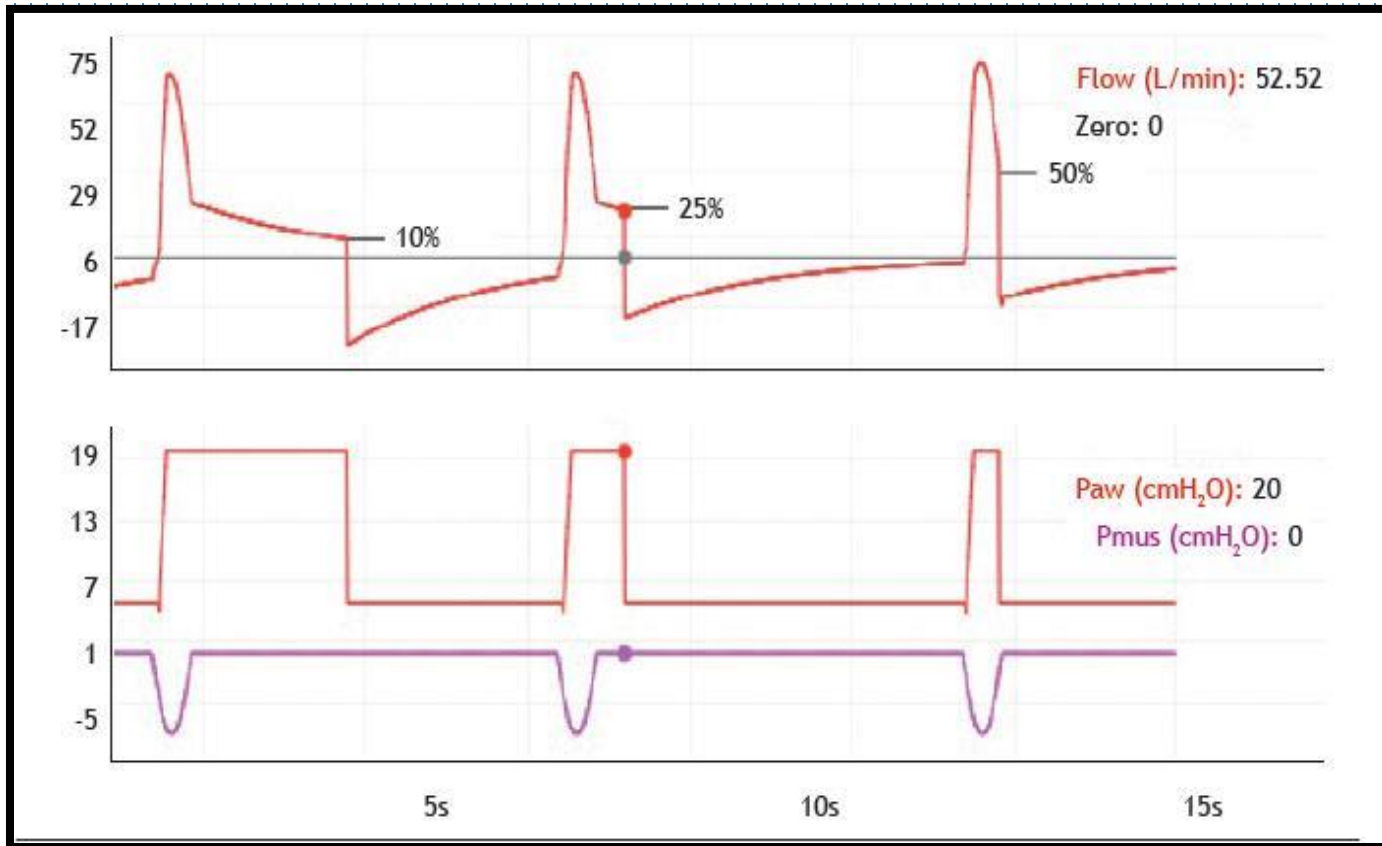
# Management of Flow Dyssynchrony

- Insufficient Flow
  - Increase gas flow (usually  $\geq 60\text{L/min}$ )
  - Consider PSV or PCV
- Strong Inspiratory Effort
  - Decrease respiratory drive
  - Assess adequacy of analgesia and sedation

# Patient-Ventilator Asynchrony (V)

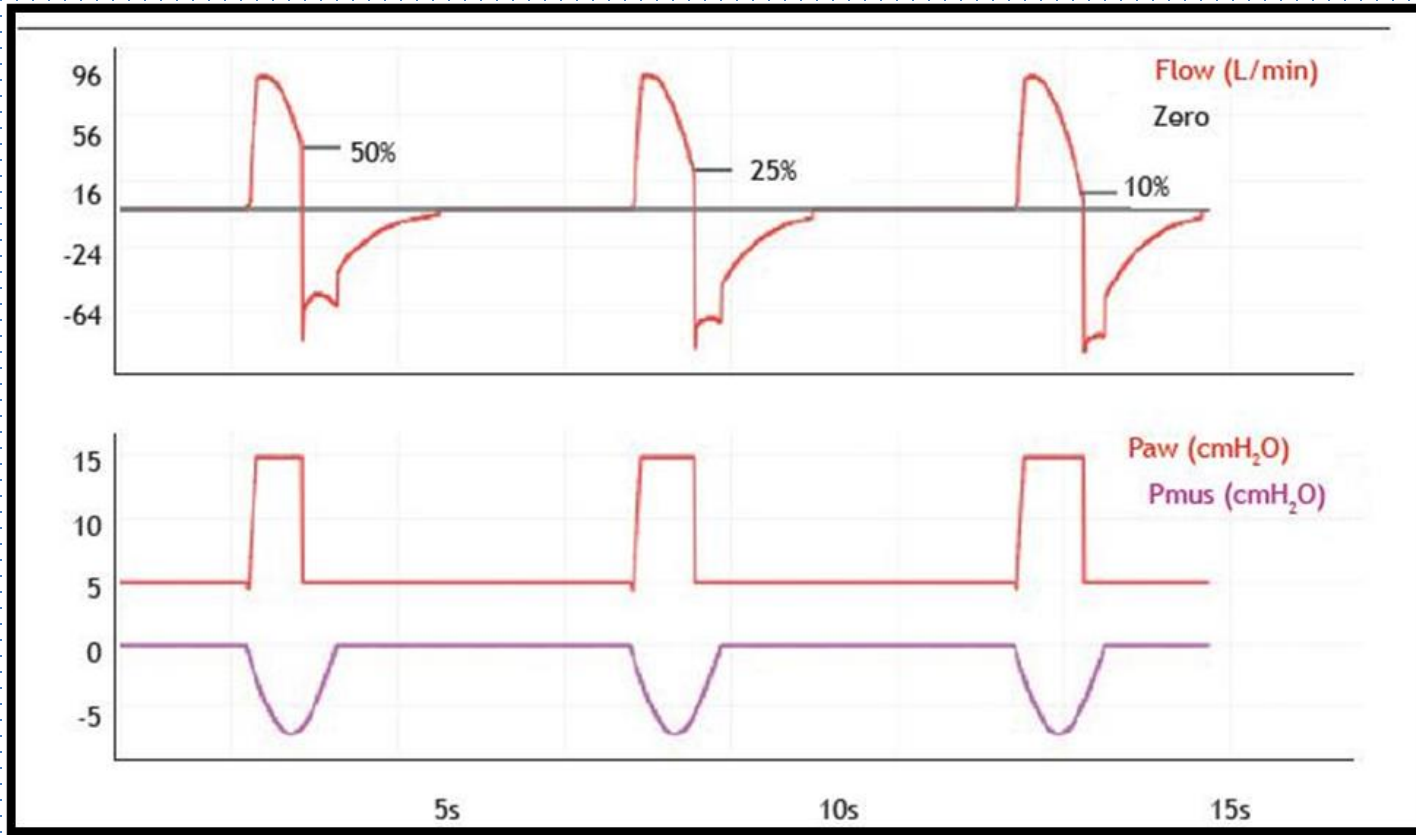
- Exhalation (Cycle) dysynchrony (too early or too late)
  - PS mode:
    - inappropriate cycling-off algorithm
  - VCV
    - volume-cycled mode, inadequate volume setting
    - time-cycled mode, inadequate I-time setting

# Delay Cycling



- Patient with COPD under PSV
- I:E = 1:1 or 1:2
- Cycle off 10% => 50%.
- I:E = 1:3~5

# Premature Cycling



- Patient with ILD under PSV
- Cycle off on 50% or 25%
- I:E = 1:3~4
- Cycle Off on 10%
- I:E = 1:1.5~2

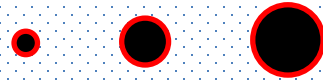
# Management of Exhalation (Cycle) dysynchrony

- PSV
  - Adjust exhalation sensitivity
  - Higher in COPD , Lower in ILD
- VCV
  - **Time-Cycled mode** : adequate I:E
  - **Volume-Cycled mode**: adequate volume

# Patient –Therapist Dyssynchrony (?)

- Patient

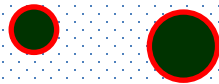
- Volume dependent
- Physiological need



Prefer VCV  
Flow dyssynchrony

- RT

- Pressure dependent
- Safety concern

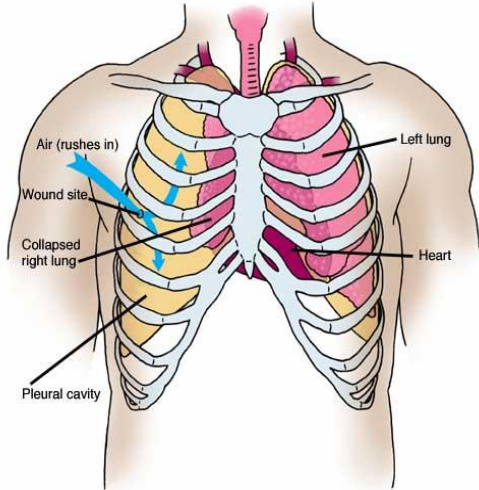
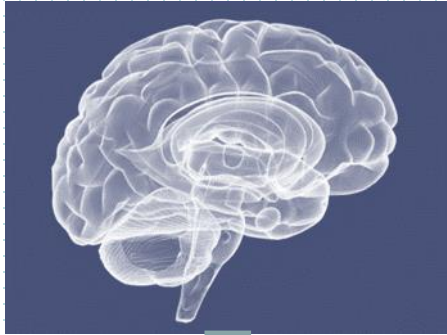


Prefer PCV  
Phase dyssynchrony

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Patient brain



Trigger

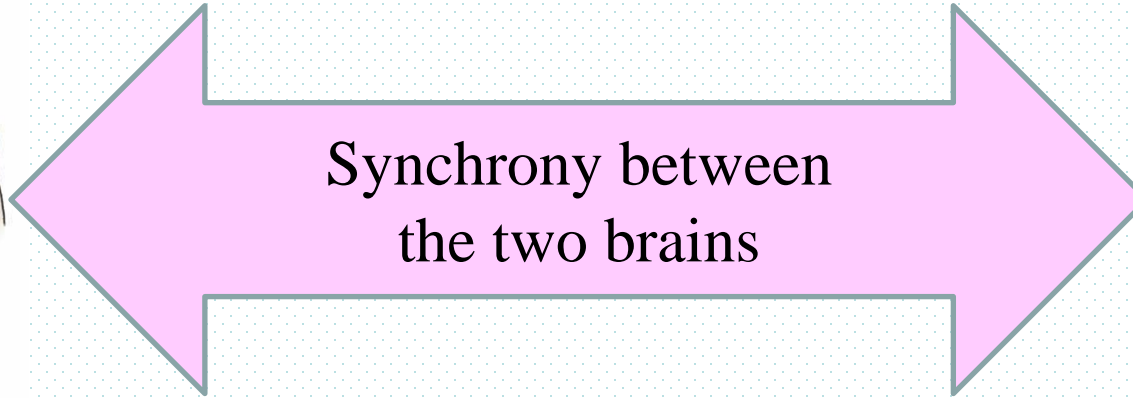


Response

Ventilator brain



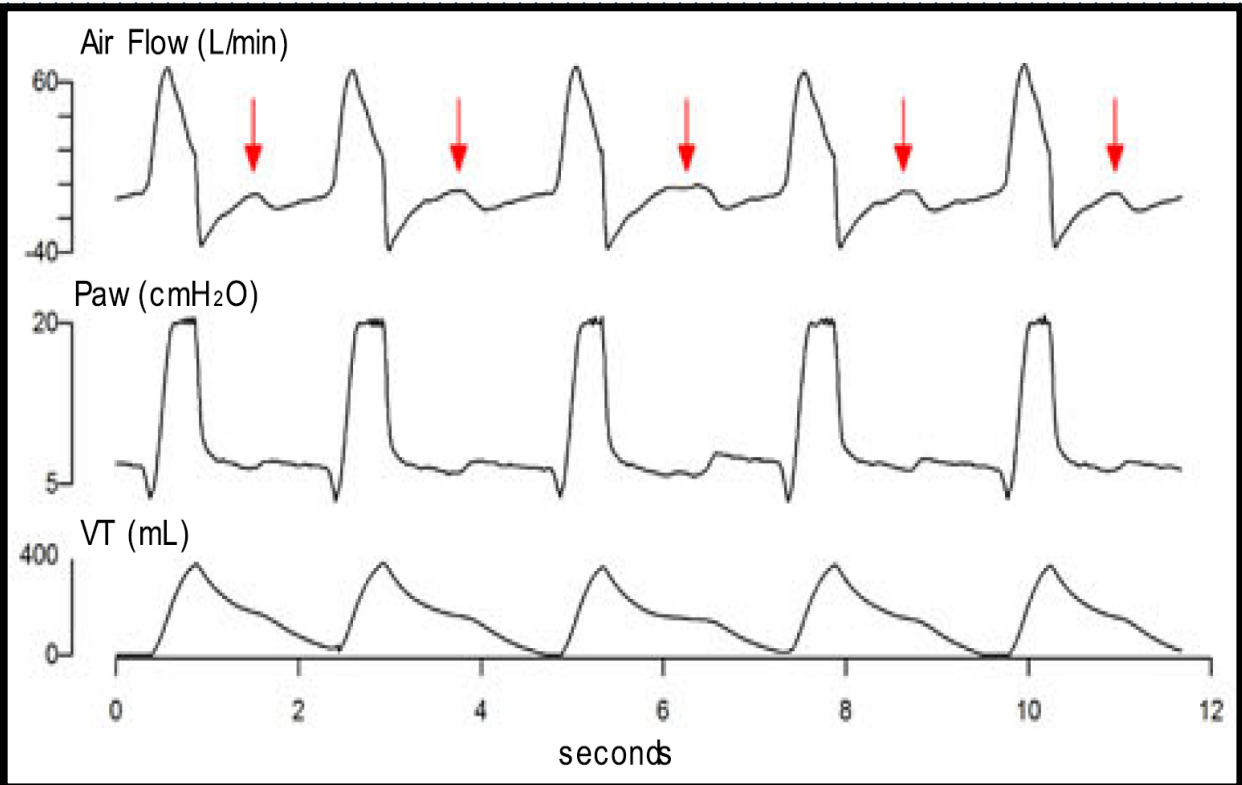
Synchrony between  
the two brains



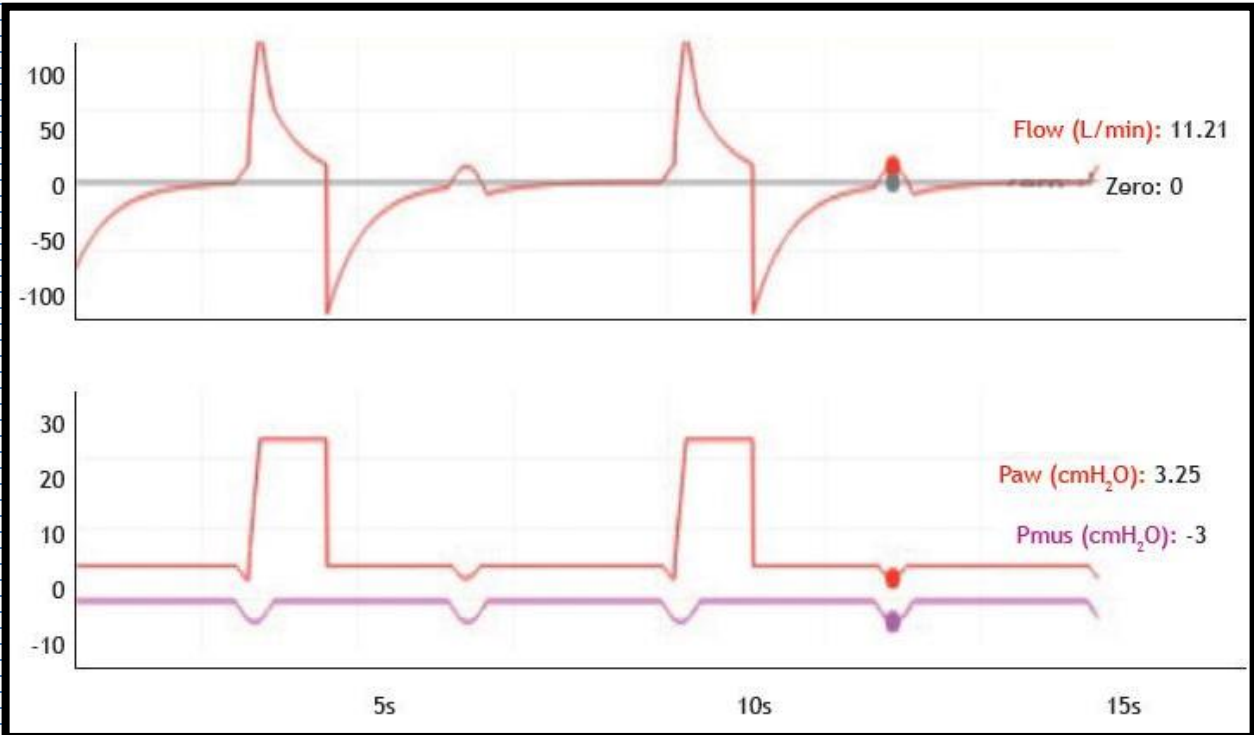
Ventilator waveforms	<ul style="list-style-type: none"> <li>Noninvasive</li> <li>Easily available</li> </ul>	<ul style="list-style-type: none"> <li>Needs expertise</li> <li>No automated analysis from ventilators</li> <li>May miss some</li> </ul>
Electrical activity of the diaphragm	<ul style="list-style-type: none"> <li>Depicts diaphragm activity</li> <li>Reliable</li> <li>Continuous and quantified</li> <li>Can be mounted on feeding tubes</li> </ul>	<ul style="list-style-type: none"> <li>Need a dedicated catheter and ventilator</li> <li>Does not detect other muscles</li> <li>Needs proper placement</li> <li>Synchrony not automatically detected</li> </ul>
Esophageal (and/or transdiaphragmatic) pressure	<ul style="list-style-type: none"> <li>Good estimate of the inspiratory effort</li> <li>Gold standard</li> <li>Can be mounted on feeding tubes</li> </ul>	<ul style="list-style-type: none"> <li>Needs catheter placement and specific monitoring</li> <li>Technical specificities (calibration procedure)</li> </ul>
Software	<ul style="list-style-type: none"> <li>Continuous</li> <li>Automatic</li> <li>Real-time analysis</li> </ul>	<ul style="list-style-type: none"> <li>Few studies</li> <li>Not yet validated</li> </ul>

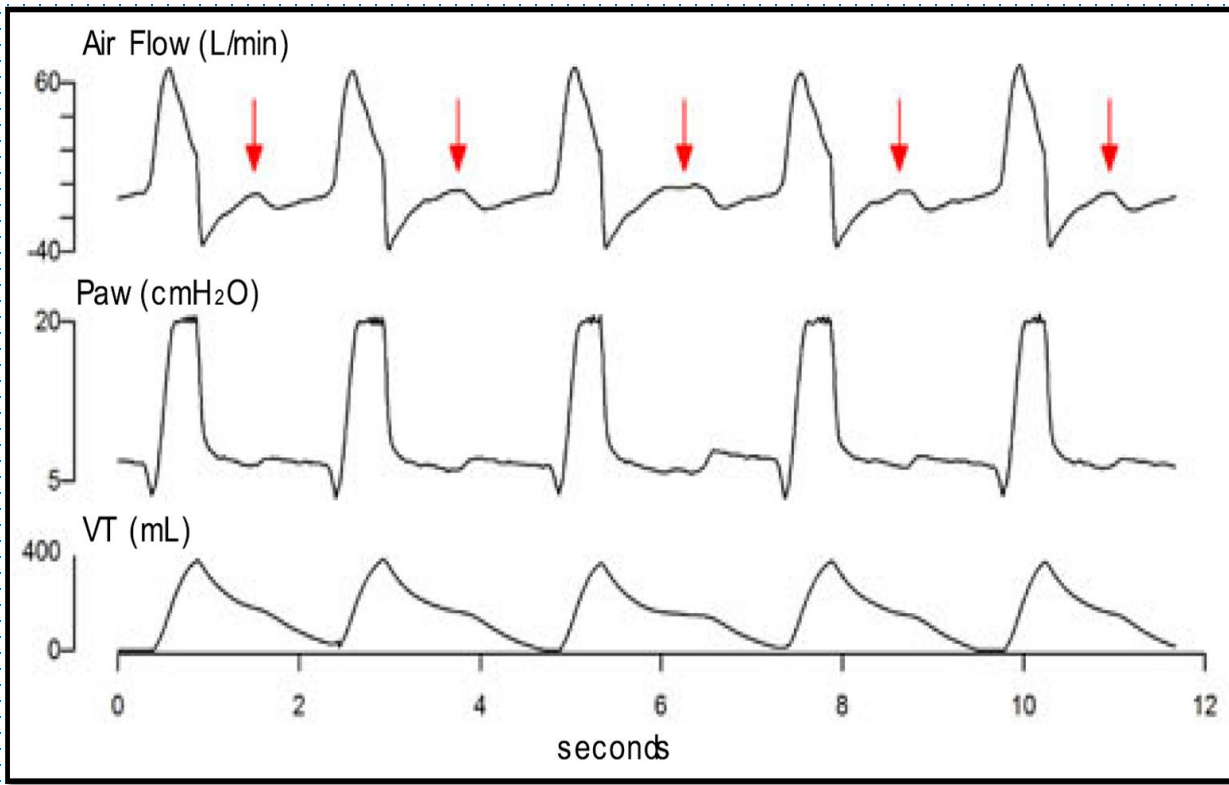
# Advanced solutions of patient ventilator asynchrony

- Advanced detector
  - Esophageal pressure
  - Diaphragm electrical activity
  - Software: continuous automatic real-time analysis
- Advanced mode
  - Ventilator better meeting patients' requirements

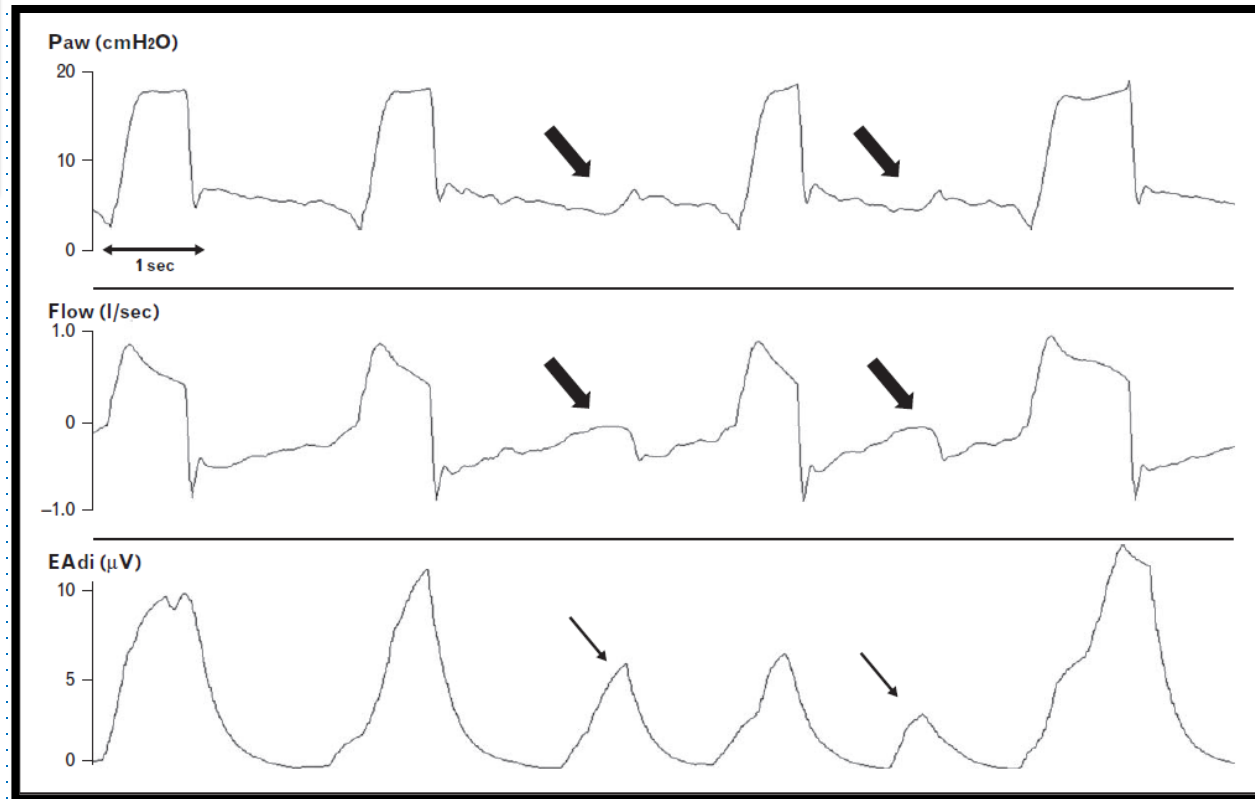


Tracings of Paw, flow, and PesO demonstrate ineffective efforts





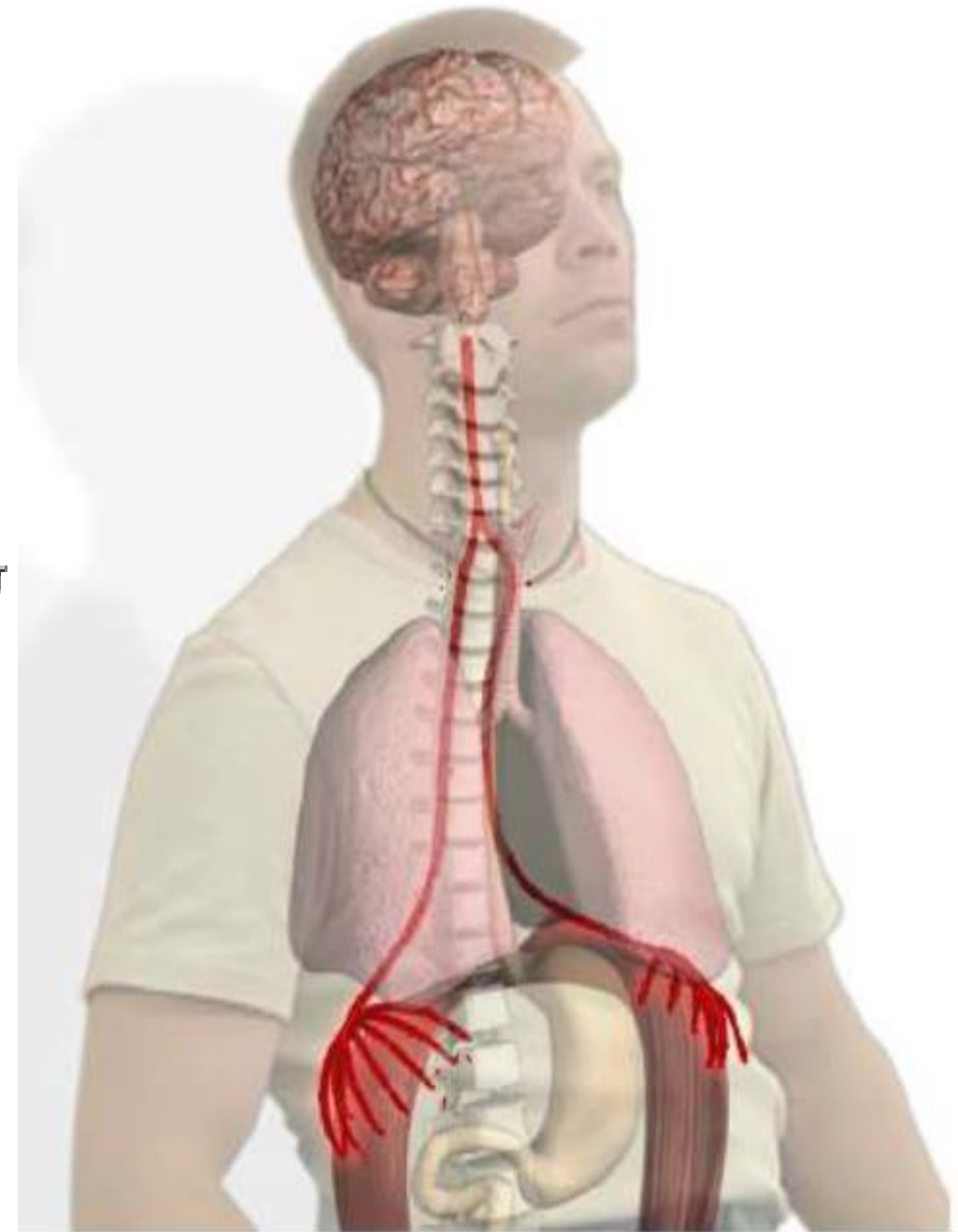
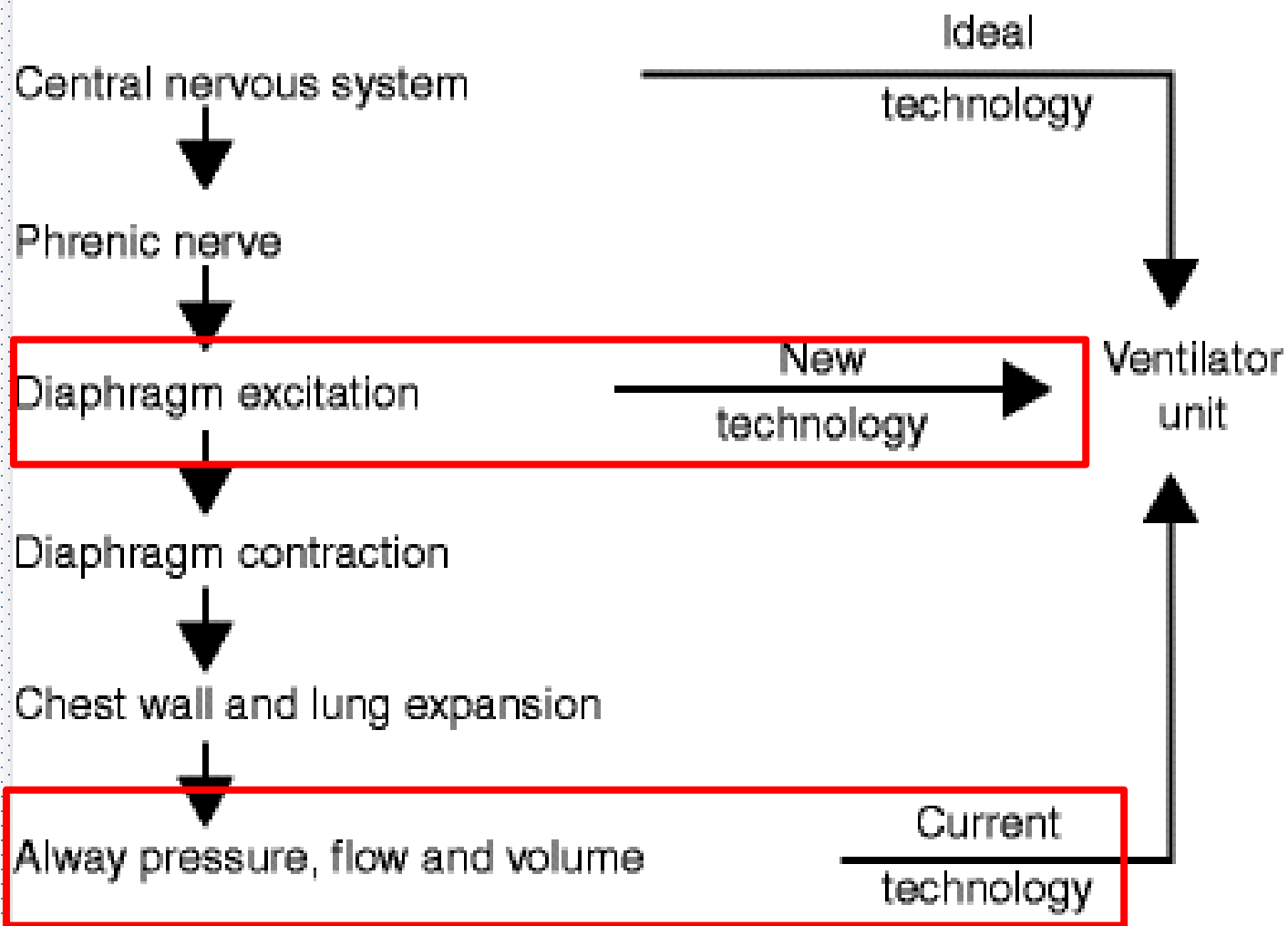
Tracings of Paw, flow, and EAdi demonstrate ineffective efforts



# Advanced modes in Mechanical Ventilation

- Improved oxygenation without VILI
  - APRV , BI-LEVEL PAP
- Improved patient ventilator synchrony
  - NAVA , PAV+
- Improved ventilator weaning
  - ASV , SMARTCARE
- Without ETT
  - Artificial Lung ( Hemolung, Novalung)

# Neuro-ventilatory coupling



# PAV (Proportional Assist Ventilation)

# PPS (Proportional Pressure Support)

- 根據病人每次呼吸所做的功,計算出呼吸系統的阻力和彈力,彈性調整提供流速(**Flow**)克服阻力和容積(**Volume**)克服彈力
- 公式  $P = \text{Flow} \times \text{Resistance} + \text{Volume} \times \text{Elastance}$ 
  - $P_{aw} = (\alpha \times \text{Flow}) + (\beta \times \text{Volume})$
  - $\alpha = \text{Volume}$  補償比例,  $\beta = \text{Flow}$  補償比例
- 根據病人每次呼吸負荷,調整 Flow / Volume, 符合病人需求
- 操作者可調整 Flow / Volume 的補償比例,協助克服呼吸系統的阻力和彈力



套上  
精緻物理

# NAVA (Neurally Adjusted Ventilation Assist)

- 呼吸時, 呼吸中樞會發出impulse, 經膈神經傳至橫膈, 刺激橫膈收縮進行呼吸
- 刺激橫膈收縮的信號和呼吸中樞發出的impulse強度成正比, 藉以控制呼吸的深度和頻率
- NAVA:
- 偵測病人的橫膈肌電氣活動(Edi或EAdi)
- 根據需求提供電氣輔助, 同步協助病人呼吸



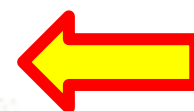
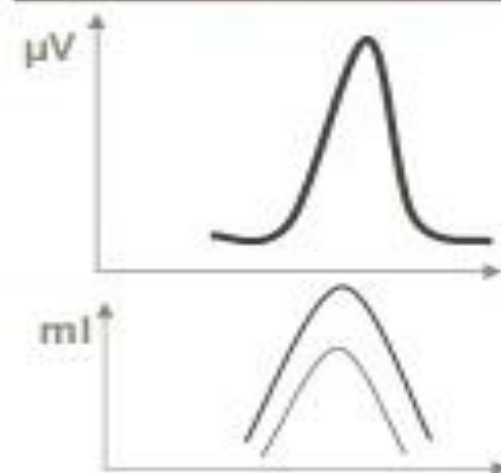
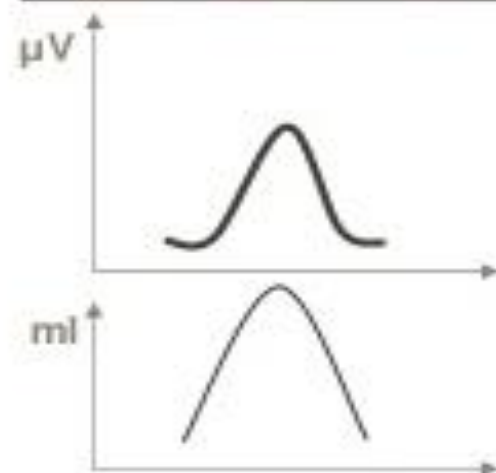
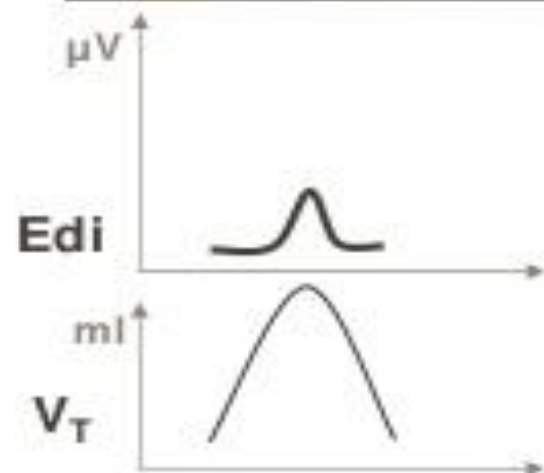
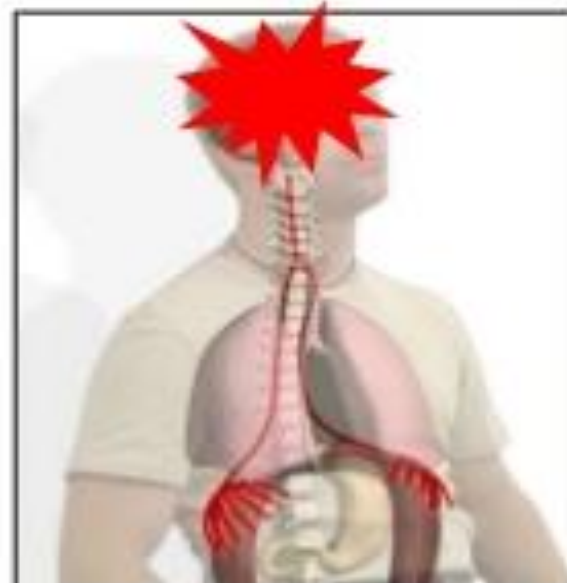
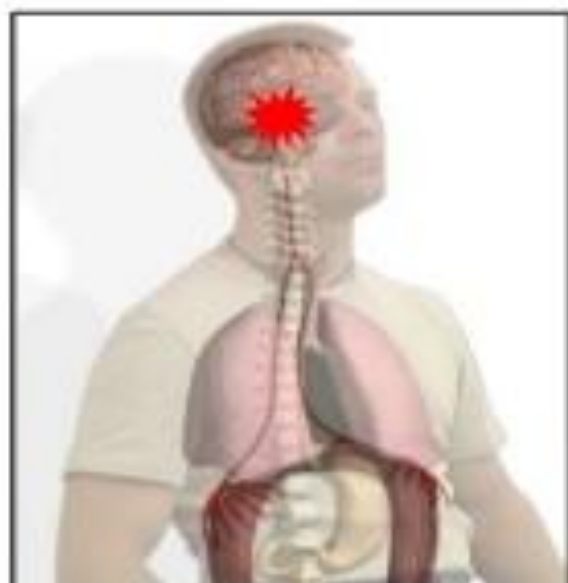
運用  
電氣生理

# Neuro-muscular coupling

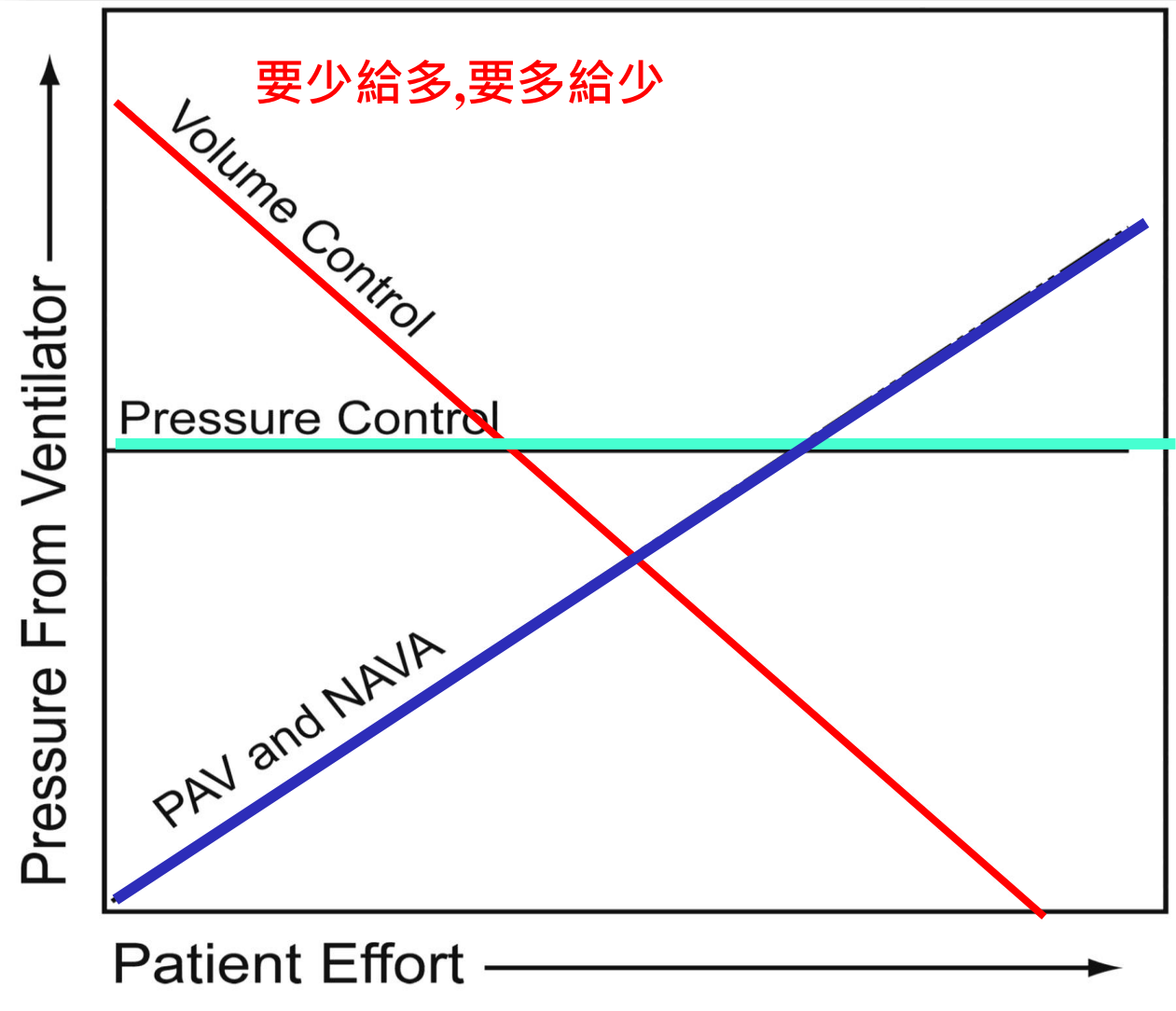
Health



Disease




# Relationship between patient effort and ventilator pressure during various ventilation modes.



要多給多,要少給少

要多要少,一視同仁

# Proportional modes versus pressure support ventilation: a systematic review and meta-analysis

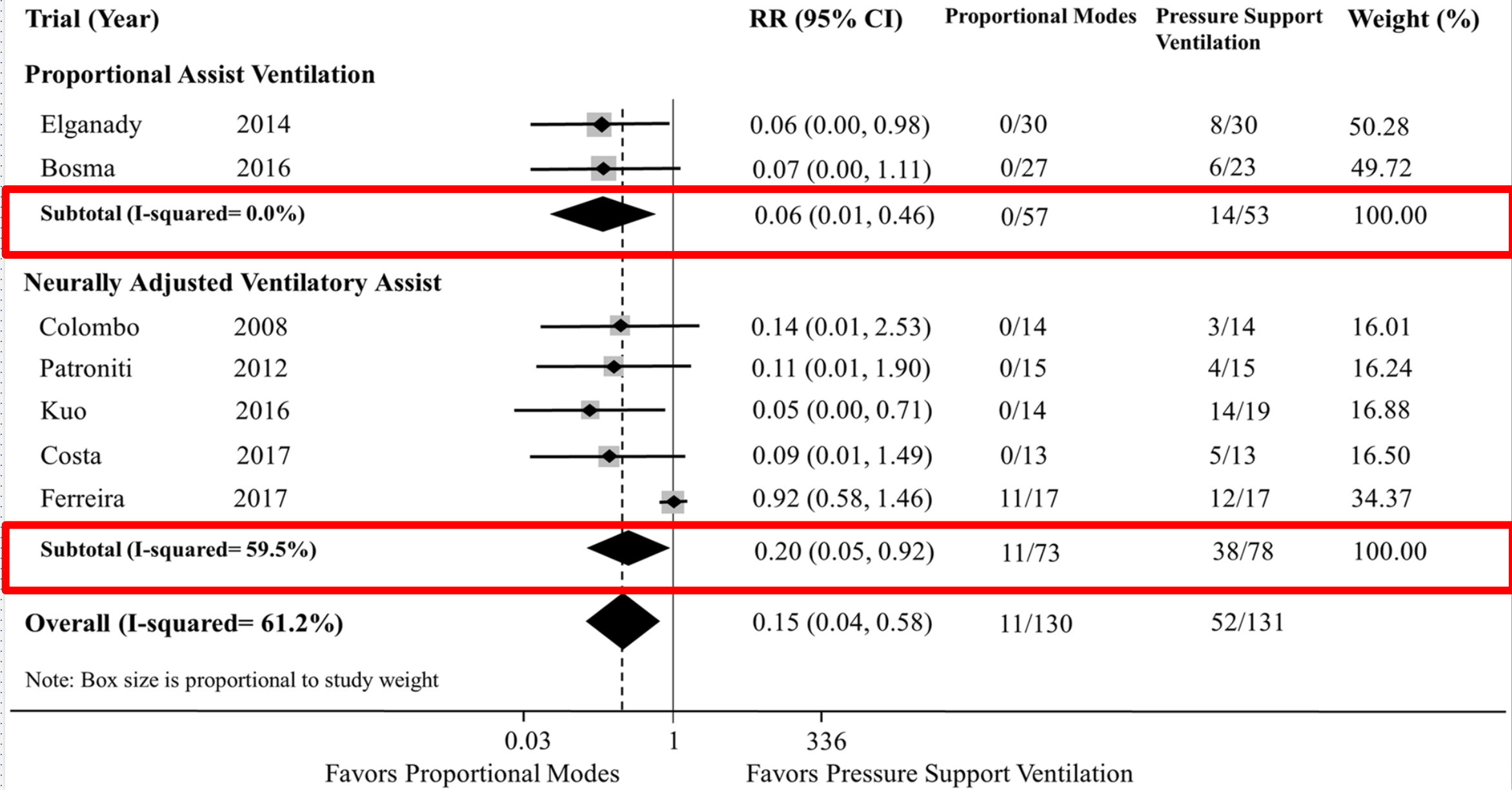
Jun Kataoka<sup>1\*</sup> , Akira Kuriyama<sup>2</sup>, Yasuhiro Norisue<sup>1</sup> and Shigeki Fujitani<sup>3</sup>

Ann. Intensive Care (2018) 8:123

- Reduction in patients with AI > 10%
- (RR 0.15; 95% CI 0.04~0.58; p= 0.006; PAV(2), NAVA(5))
- primary outcomes (1) asynchrony index (2) weaning failure (3) duration of MV

# Relative risk of asynchrony index (AI)

**b**



# Proportional Assist Ventilation VS Neurally Adjusted Ventilatory Assist.

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## PAV

Requires measurement of airway pressure, flow, and volume, and calculation of elastance and resistance

No additional hardware needed during application

Available invasively and noninvasively (different ventilators)

Recommended for patients  $> 20$  kg

Affected by leaks (current invasive application) and intrinsic PEEP

## NAVA

Requires diaphragm electromyography (EMG)

Requires a special nasogastric catheter

Available invasively and noninvasively on the same ventilator

Useful in neonates, children, and adults: no weight restriction

Unaffected by leaks or intrinsic PEEP

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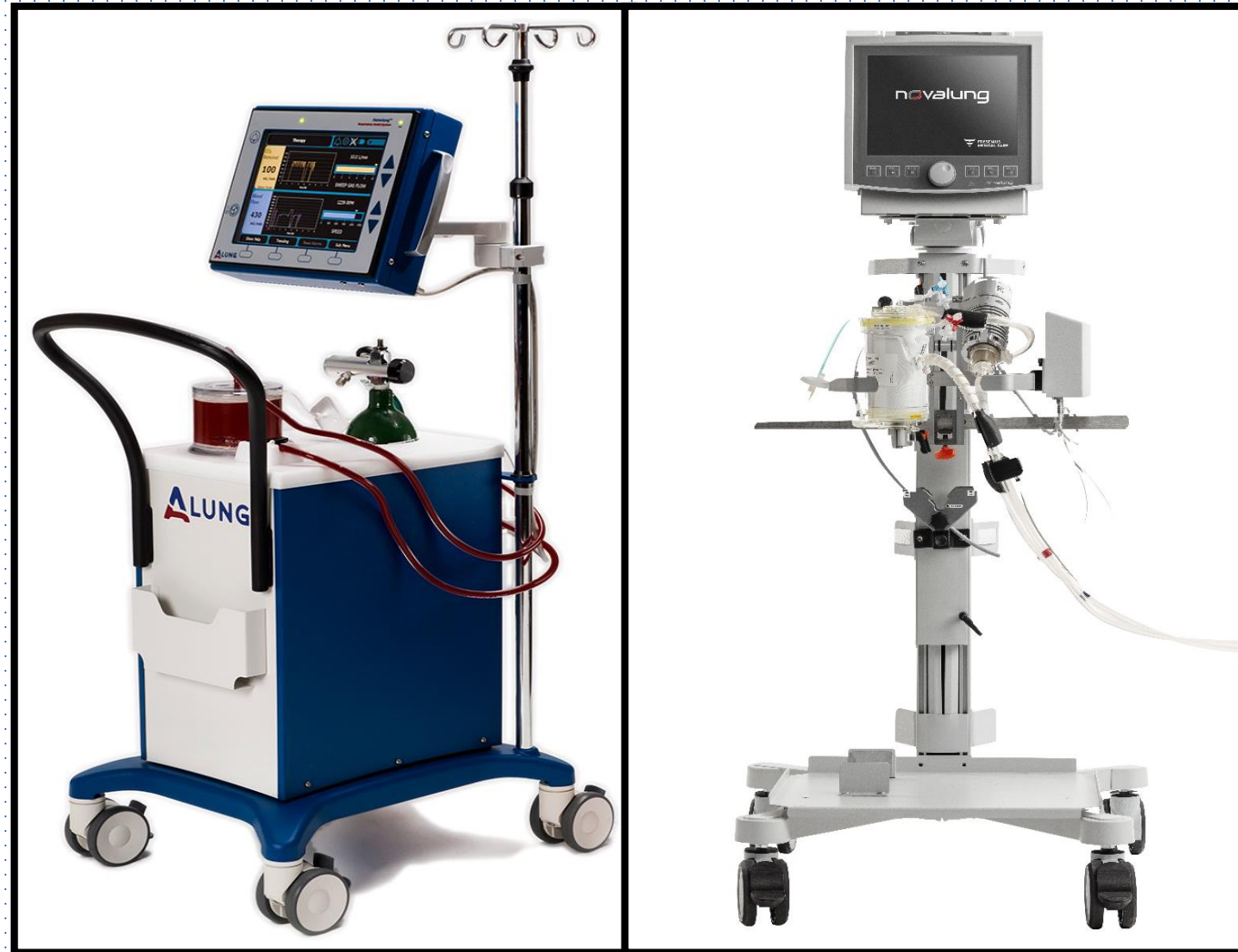
PAV = proportional assist ventilation

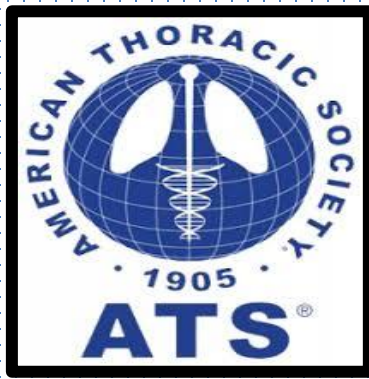
NAVA = neurally adjusted ventilatory assist

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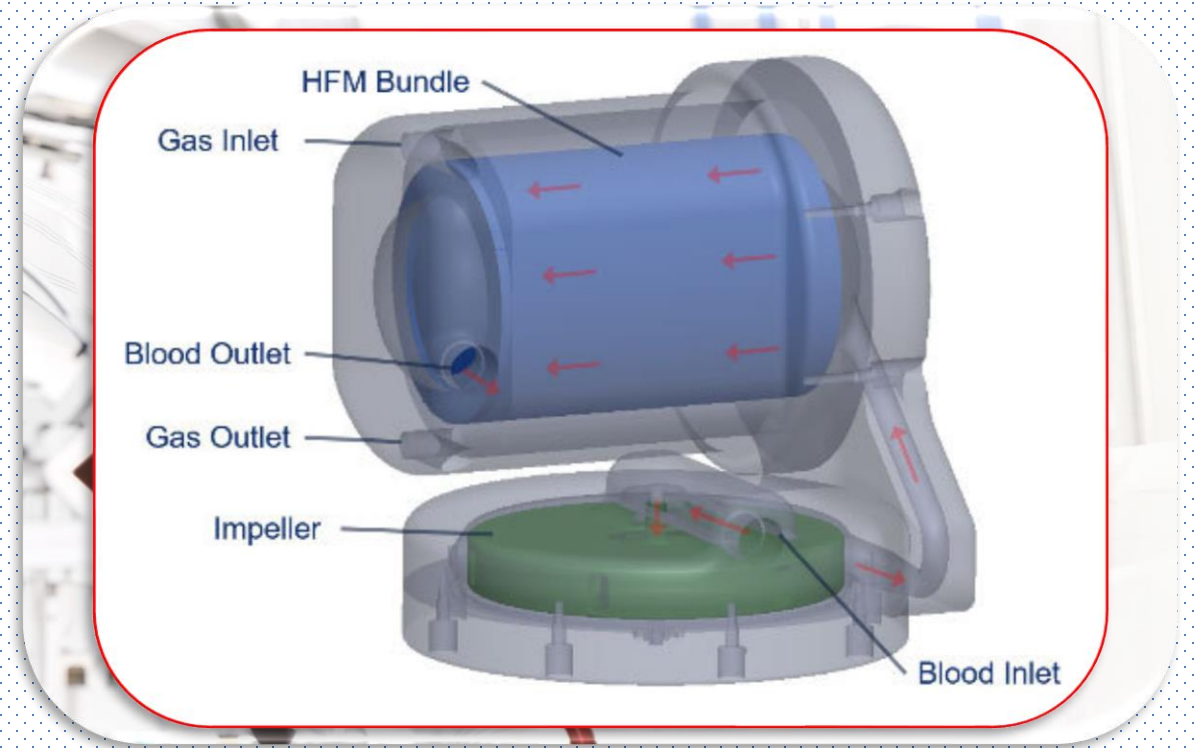
# Future in Mechanical Ventilation

- MV Without ETT (Artificial Lung)
  - Hemolung<sup>®</sup> RAS ( **ALUNG** )
  - Novalung ( Xenios )
- NO
  - VILI / Asynchrony / VAE
- BUT
  - Catheter Infection/ Bleeding/  
Airway Hygiene





# Artificial Lung



Extracorporeal Lung Support

Respiratory Dialysis



# FDA OKs emergency use of Alung's Hemolung for COVID-19 patients



*Hemolung. Credit: Alung Technologies Inc.*

By Meg Bryant No Comments

April 24, 2020

Pittsburgh-based [Alung Technologies Inc.](#) has received emergency use authorization from the U.S. FDA for its Hemolung Respiratory Assist System (RAS) to treat lung failure caused by COVID-19. The technology could help to ease demand for ventilators, which have been in short supply in coronavirus hot spots, and provide an alternative for patients who can't tolerate mechanical ventilation.

Hemolung functions like a dialysis machine, removing carbon dioxide directly from the blood and recirculating it with oxygen. It was originally developed to treat patients with chronic obstructive pulmonary disease (COPD) and acute respiratory distress syndrome (ARDS).

The EUA allows for use of Hemolung RAS to treat lung failure in COVID-19 patients as an “adjunct to noninvasive or invasive mechanical ventilation to reduce hypercapnia and



**Thanks For Your Listening**

