台灣胸腔暨重症加護醫學會 機械通氣訓練課程 (北區)

Monitoring and **Troubleshooting** for Patients with Mechanical Ventilation

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Part 1: Monitoring
during mechanical ventilation

- Accuracy of measurements
- Fidelity of recordings
- Other barriers to accurate data gathering
- Clinical applications

Major reference: Martin J. Tobin. Principle and Practice of Mechanical Ventilation. 3rd edition

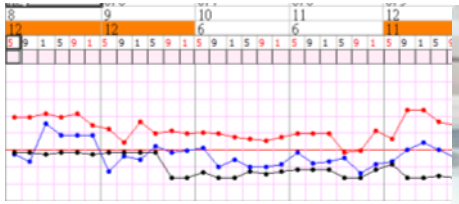
Part 2: Troubleshooting

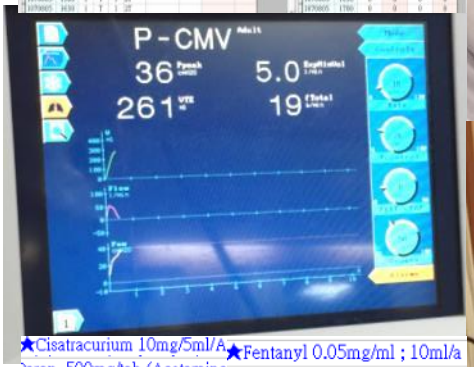
- Patient-related problems
- Ventilator-related problems
- Patient-Ventilator interactions
- Other situation (cases)

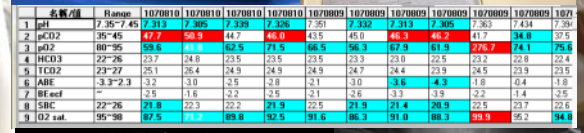
Scope: Conventional modes,
Common measurements

Major reference:
Daniel Gilstrap *et al*, Patient-Ventilator interactions. AJRCCM 2013, 188: 1058-1068. Clin Chest Med 2016, 27:669-681.

Monitoring
During Mechanical Ventilation

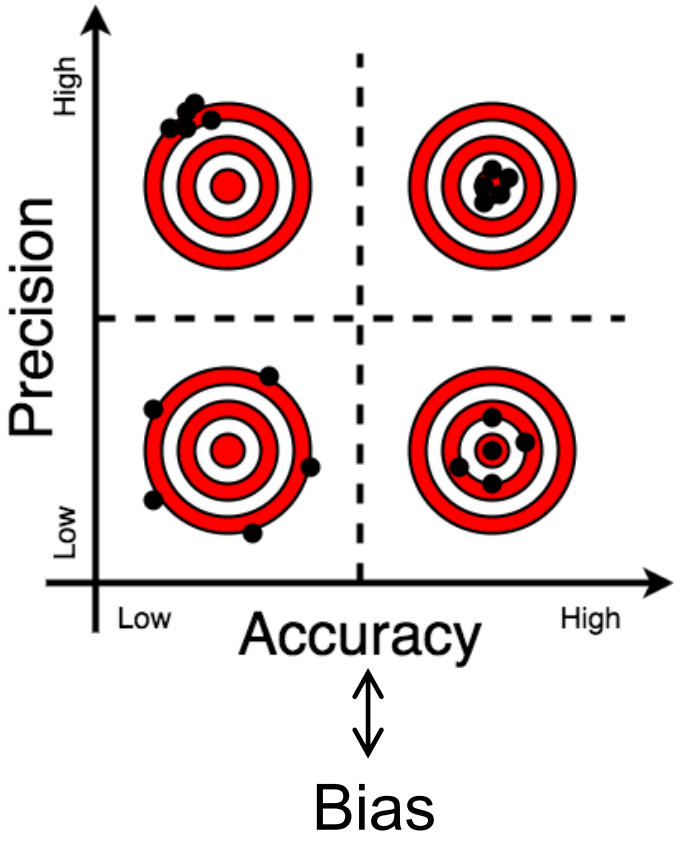






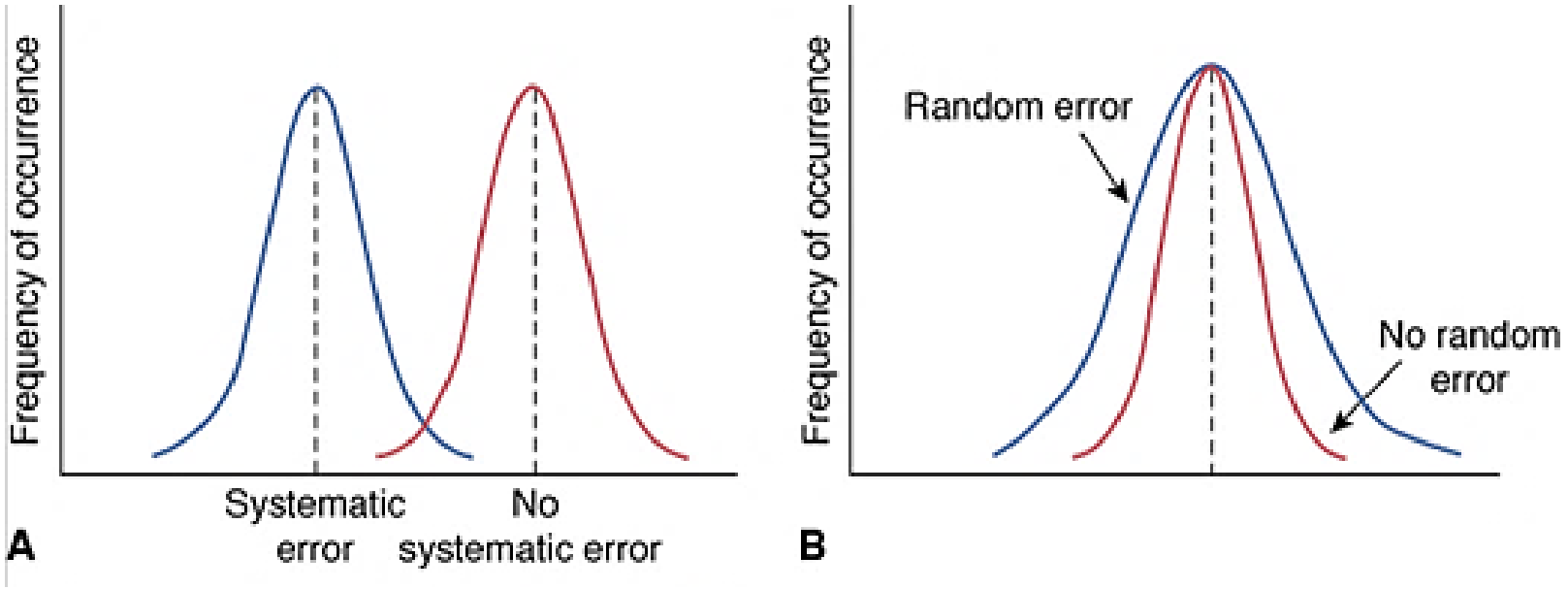
Accuracy of Measurements

- Fundamentals of measurement Theory
  - Accuracy
  - Precision
  - Linearity
  - Calibration

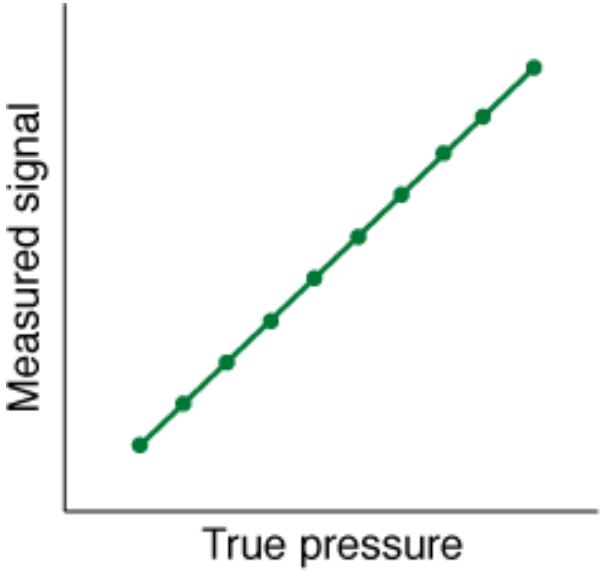


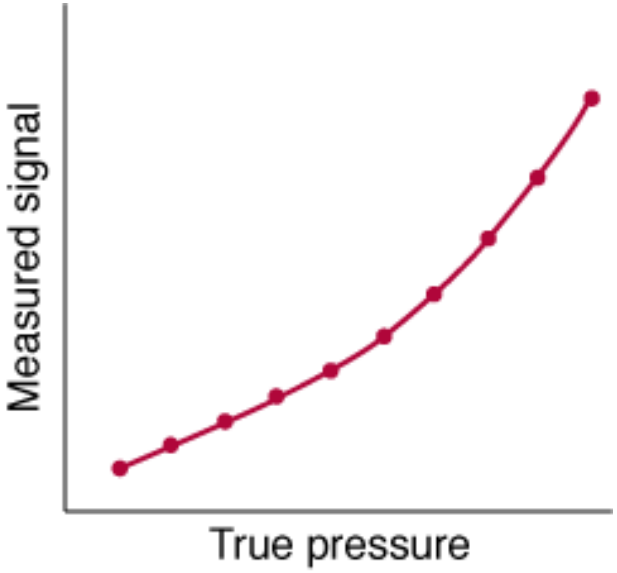
Accuracy of Measurements

- Source of Measurement Error during Monitoring
  - Systemic error (bias)
  - Random error (variability; imprecision)



Linearity

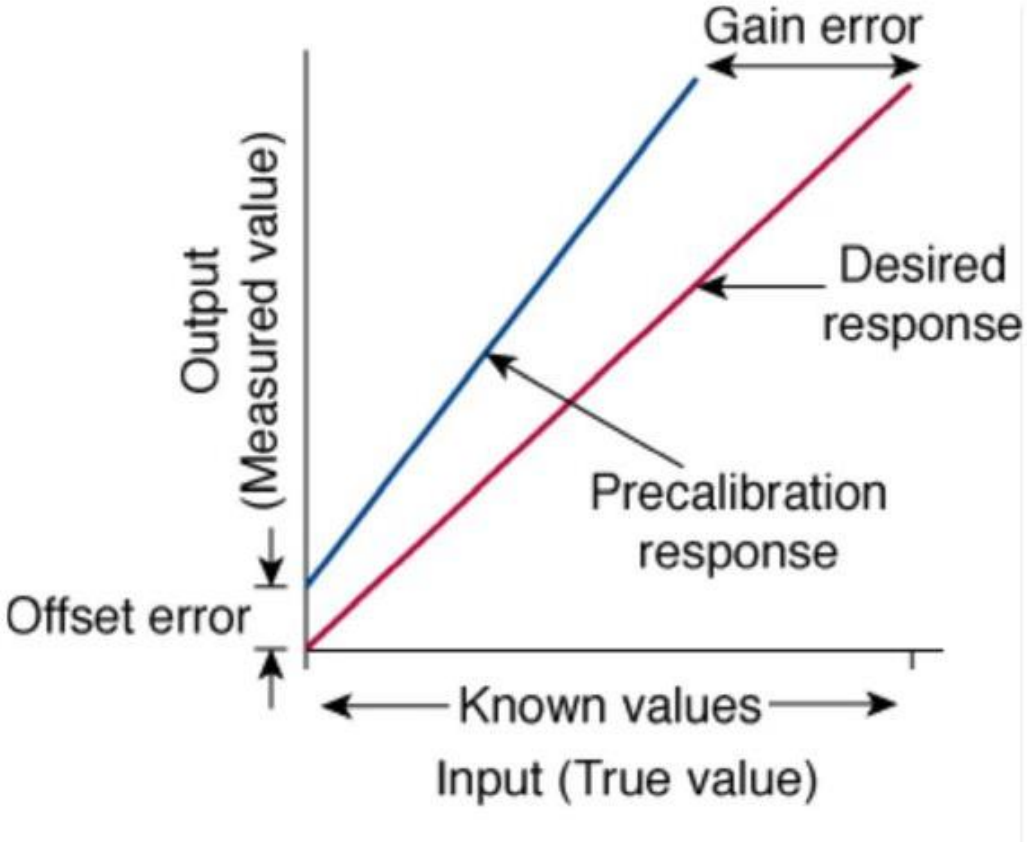




Source: Tobin MJ: *Principles and Practice of Mechanical Ventilation, 3rd Edition:* www.accessanesthesiology.com

Calibration

To reduce systemic error



Source: Tobin MJ: *Principles and Practice of Mechanical Ventilation, 3rd Edition:* www.accessanesthesiology.com

Measurement Error during Monitoring

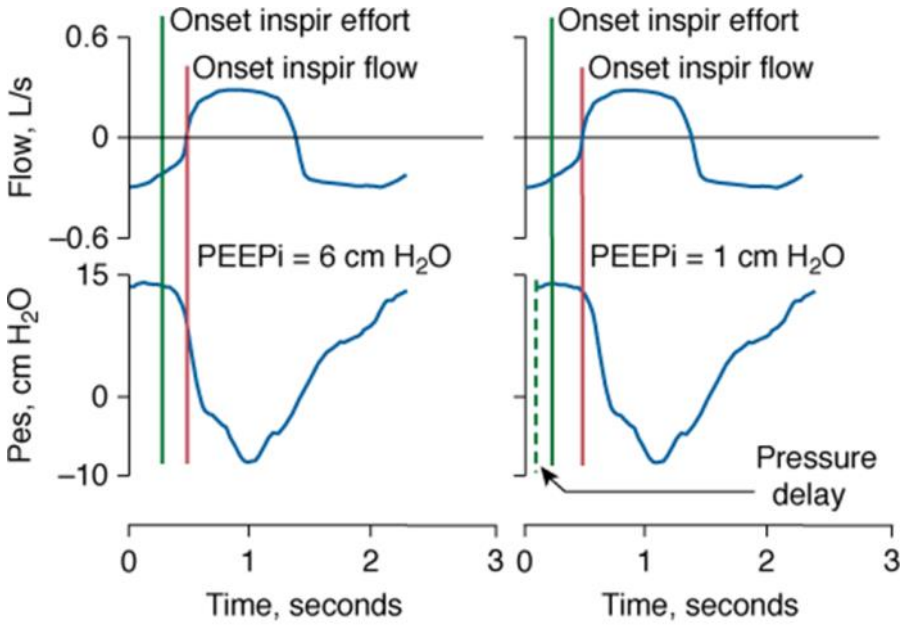
Sources of Systemic Error

- Zero offset error
  - Calibration
  - Drift error
- Range error
- Response time
- Frequency response
  - The ability to accurately measure an oscillating signal

Measurement Error during Monitoring

Sources of Systemic Error

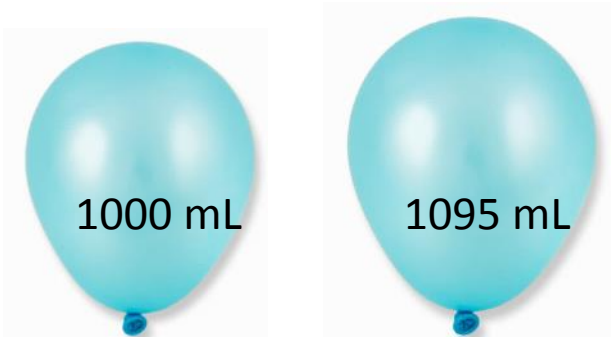
- Alignment of Signals
  - Phase lag between 2 signals
    - Determine compliance and resistance (Flow and Pressure)
    - PEEPi using an esophageal balloon-catheter system



Source: Tobin MJ: *Principles and Practice of Mechanical Ventilation, 3rd Edition:* www.accessanesthesiology.com

Measurement Error during Monitoring
Sources of Systemic Error

- Variable Conditions between Calibration and Data Collection
  - Temperature
  - Humidity
  - Pneumatochography
    - Test tubing vs.
      Patient's ventilator tubing
      (air turbulence and resistive element)
    - Underestimate:
      Flow ~10%
      Volume ~15%



$$PV = nRT$$

AJRCCM 1996; 154:913-917

Measurement Error during Monitoring

Sources of Random Error

- Noise → False alarm…
  - Low SpO2 alarm: 35% from the probe slipping off the patient's skin
  - All ICU machine alarms: about 86% were false (2528/2942 events)

- Nonlinearity

TABLE 2. Relative error of the 9000 IV at different F_{IO_2} values

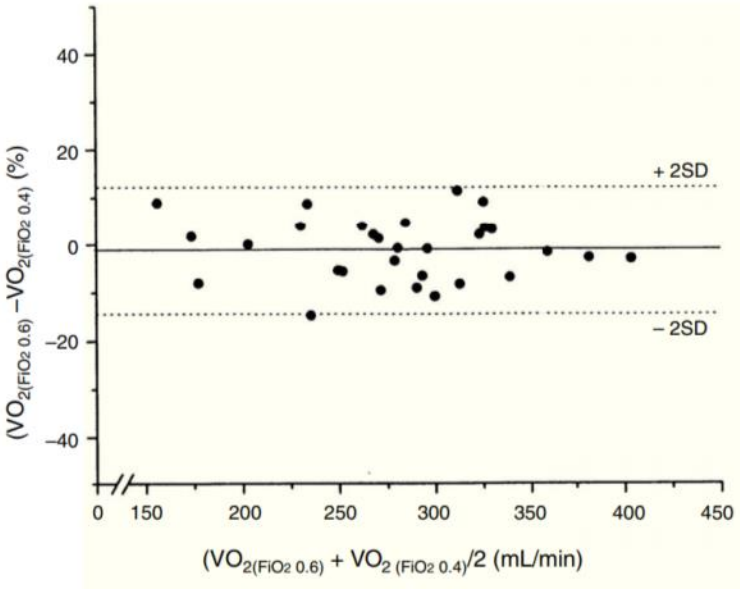
F_{IO_2}	$\dot{V}O_2$ (mean ± SEM, ml/min)		*p*-Value	Relative Error[a] (± SEM)
	Calculated	Measured		
0.22 (n = 36)	440.4 ± 22.8	447.5 ± 22.9	$p < .002$	2.6 ± 0.3%
0.40 (n = 36)	446.8 ± 26.2	461.6 ± 27.2	$p < .001$	3.5 ± 0.4%
0.60 (n = 36)	438.2 ± 24.1	462.0 ± 24.5	$p < .001$	5.9 ± 0.5%
0.80 (n = 36)	442.5 ± 12.7	509.5 ± 29.1	$p < .001$	16.9 ± 1.3%
Total (n = 144)	442.5 ± 12.7	470.2 ± 13.0	$p < .001$	7.2 ± 0.6%

[a] Relative error = $\frac{\text{measured } \dot{V}O_2 - \text{calculated } \dot{V}O_2}{\text{calculated } \dot{V}O_2} \times 100$

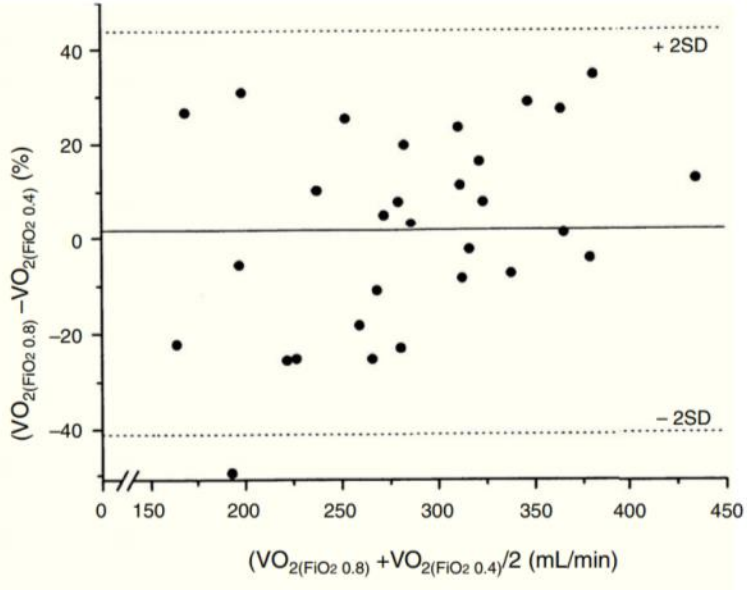
Crit Care Med. 1997;25:614-619
Crit Care Med. 1986; 14:807-811

E-COVX monitor evaluates VO_2 in critical patients with mechanical ventilation

FiO_2 0.4 vs. 0.6



FiO_2 0.4 vs. 0.8



Bland–Altman plot

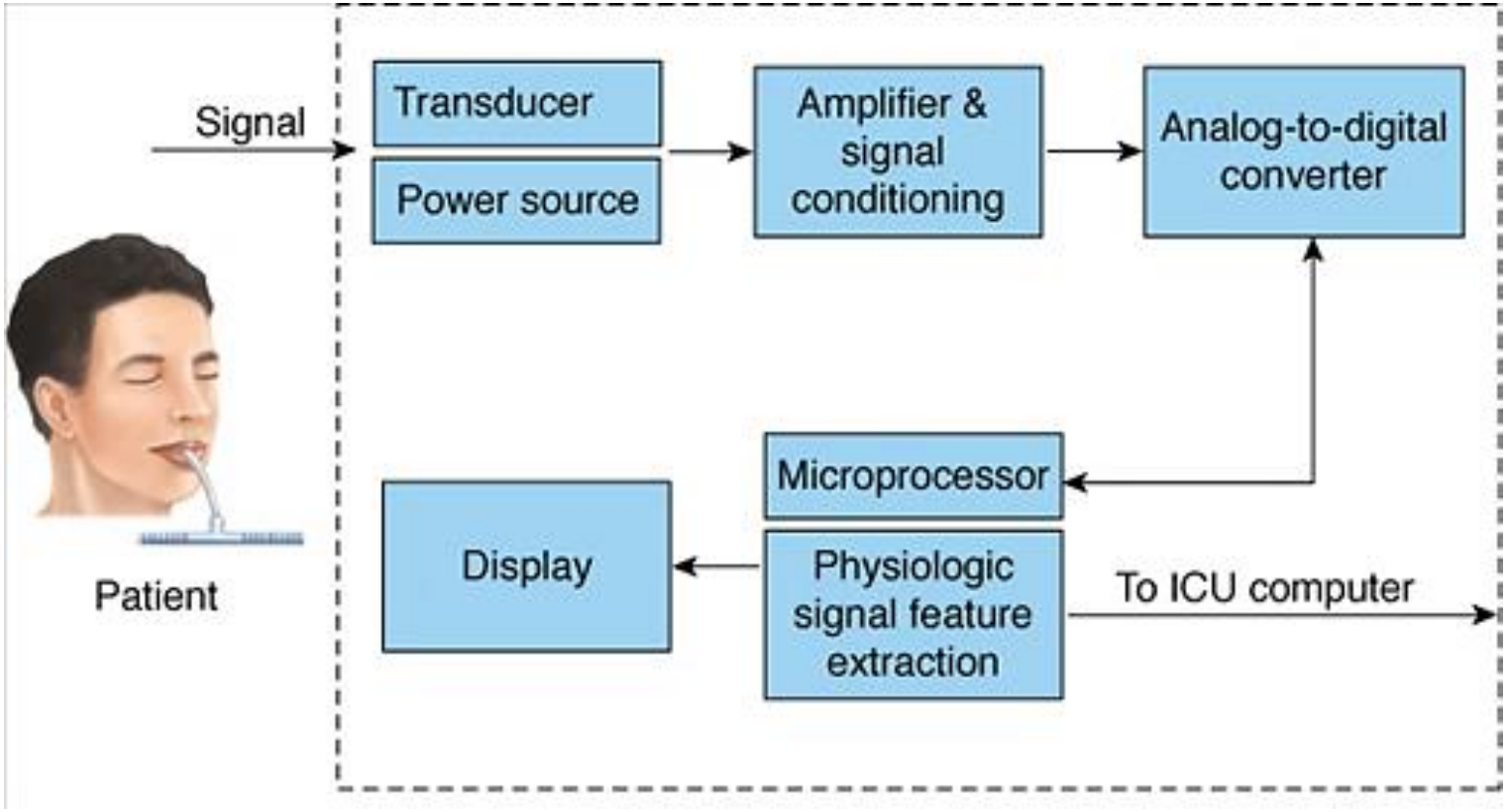
Med Intensiva. 2017;41:461---467.

Measurement Error during Monitoring
Sources of Random Error

- Human Error
  - Timing of observation and record
  - Patient cooperation
    - PEEPi: could be quantified in only 30% attempts
    - Maximal inspiratory pressure: 28% increase after coaching

Source: Tobin MJ: *Principles and Practice of Mechanical Ventilation, 3rd Edition*: www.accessanesthesiology.com

Fidelity of Recordings



Source: Tobin MJ: *Principles and Practice of Mechanical Ventilation, 3rd Edition:* www.accessanesthesiology.com

Other Barriers to Accurate Data Gathering-1

- Physiologic variation
  - Breath-to-breath variability in V_T (coefficient of variation):
    - Healthy young adult: 33.0 ± 14.9%
    - Healthy older: 44.0 ± 14.7%
- Inherent limitations of monitors
- Different techniques for measuring the same physiologic process
  - Paradoxical change of PaO_2 and SpO_2 (~25% of measurements)
    - Therapeutic decision based on SpO_2 differed from decisions based on PaO_2 on 16% occasions

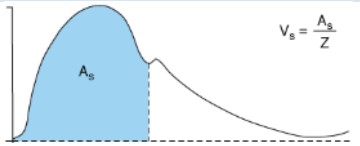
Source: Tobin MJ: *Principles and Practice of Mechanical Ventilation, 3rd Edition:* www.accessanesthesiology.com

Other Barriers to Accurate Data Gathering-2

- Monitoring the right physiologic phenomenon
  - Primary goal of ventilator: **Rest the respiratory muscles.**

What we **NEED**	What we **CAN** monitor
Activity of the respiratory muscles	**Arterial blood gas**
Cardiac output, Stroke volume	A-line contour technique
Preload, LVED	Central venous pressure
Portal hypertension	Serum-Ascites Albumin Gradient

檢驗項目	檢驗報告	單位
Blood Gas		
pH	7.453	
pCO2	31.3	mmHg
pO2	116.9	mmHg
HCO3	21.4	mmol/L
TCO2	22.4	mmol/L
ABE	-0.9	mmol/L
BEecf	-2.5	mmol/L
SBC	23.2	mmol/L
O2 sat.	98.7	%



Clinical Applications

- Enhance understanding of pathophysiology
- Aid with diagnosis
- Guide management
- Avoid complications
- Provide alarms
- Assessment of trends

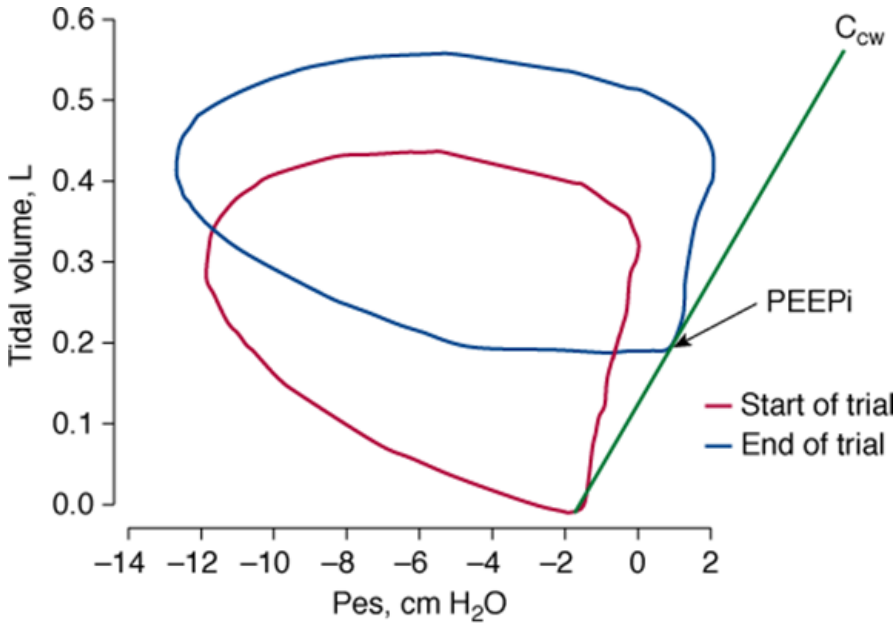
Enhance Understanding of Pathophysiology

- Weaning trial

Measurements:
Flow
Esophageal pressure

Patient effort

Resistive
Elastic
PEEPi

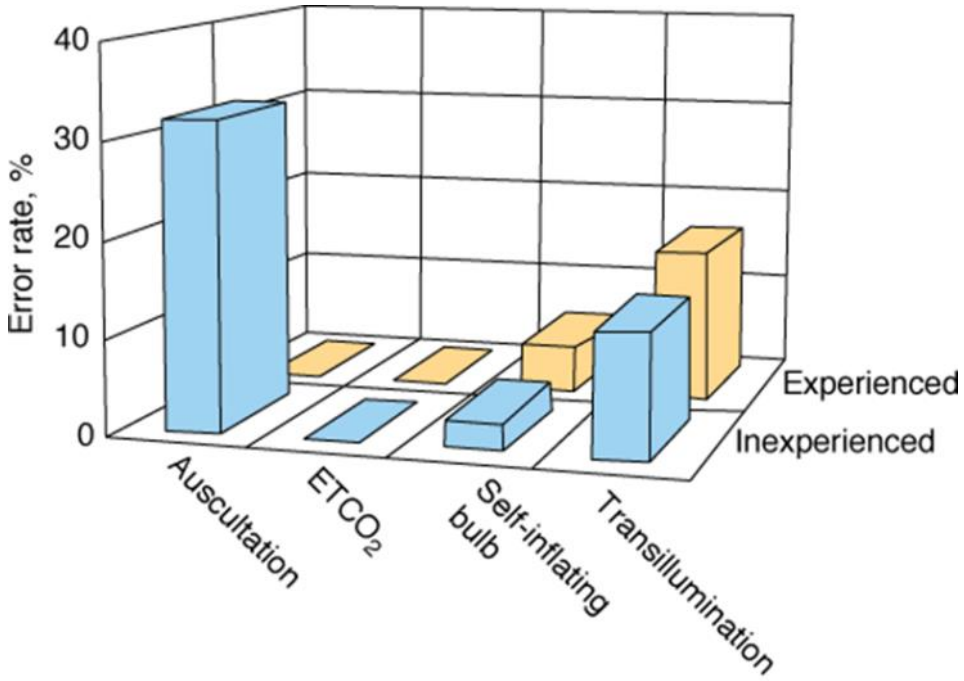


Source: Tobin MJ: *Principles and Practice of Mechanical Ventilation, 3rd Edition:* www.accessanesthesiology.com

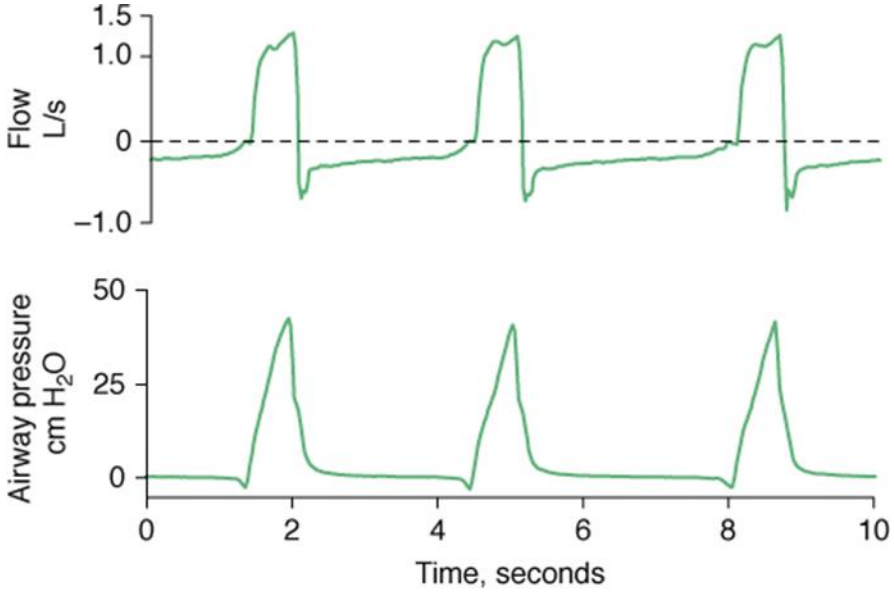
AJRCCM 1997;155:906-915
AJRCCM 2005;171:1251-1259

Aid with Diagnosis

To verify tracheal tube position

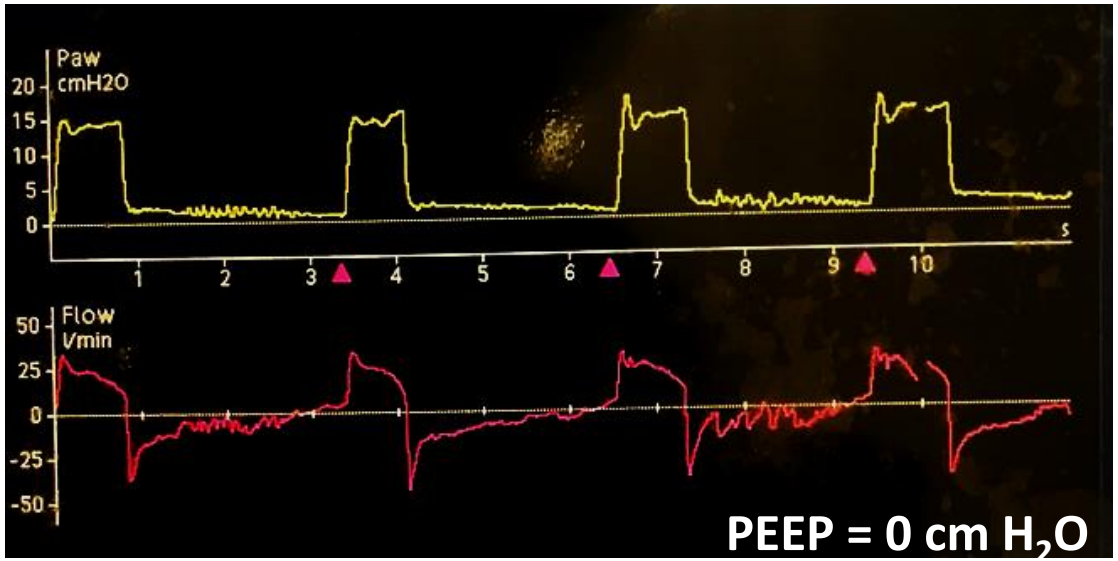


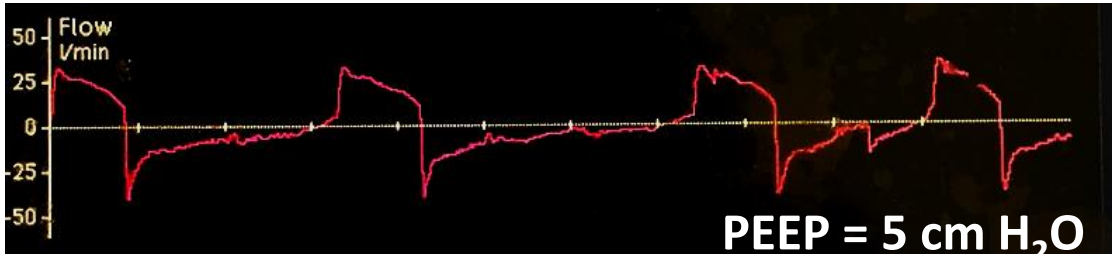
To identify PEEPi

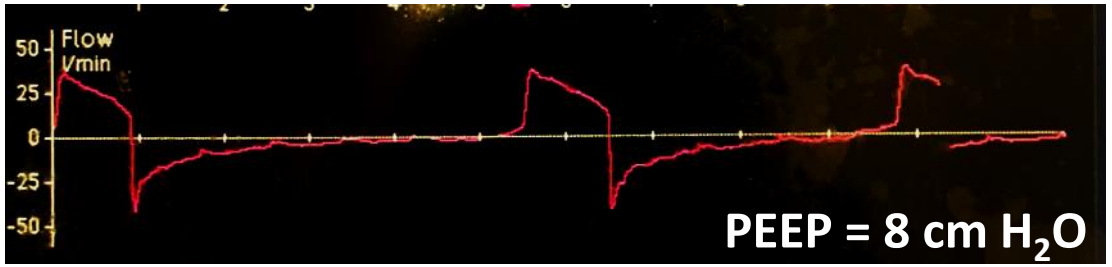


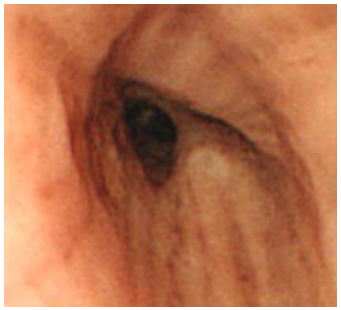
Anesth Analg. 1999;21:522-536

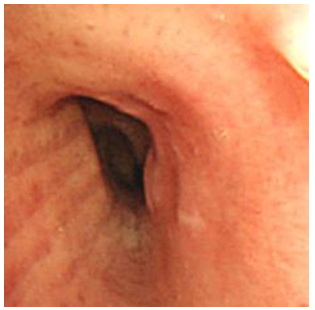
Aid with Diagnosis











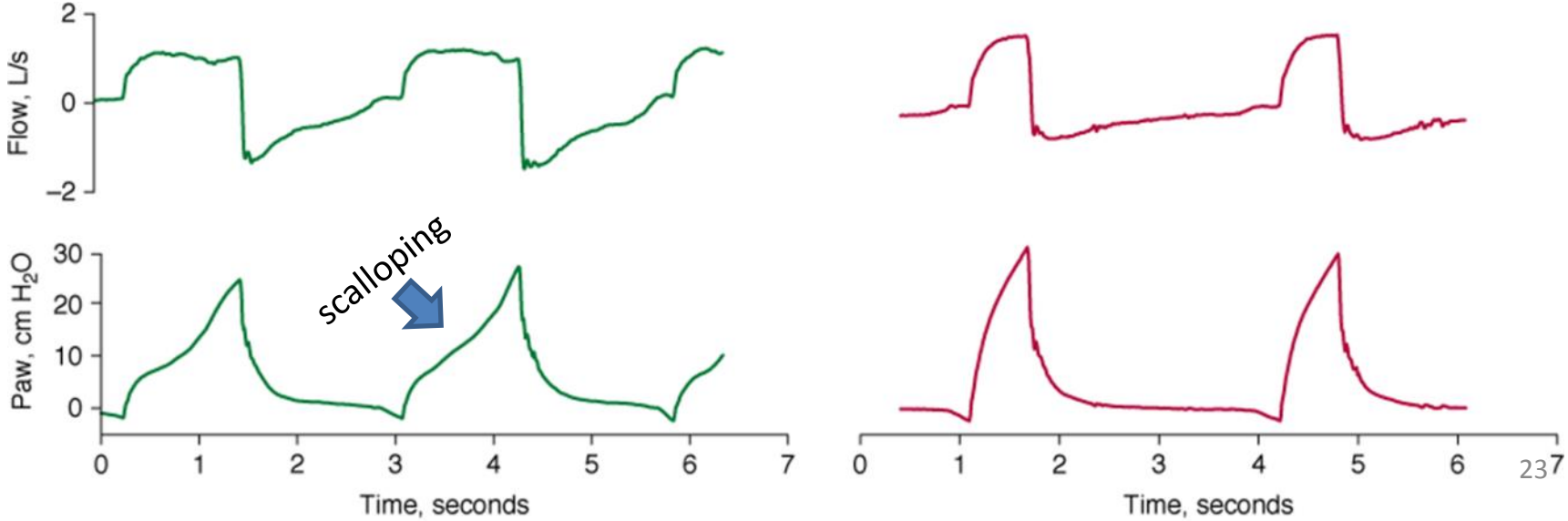
Bronchomalacia and excessive dynamic airway collapse, with **expiratory flow oscillations** and **notching.**

Aid with Diagnosis

To identify bronchopleural fistula

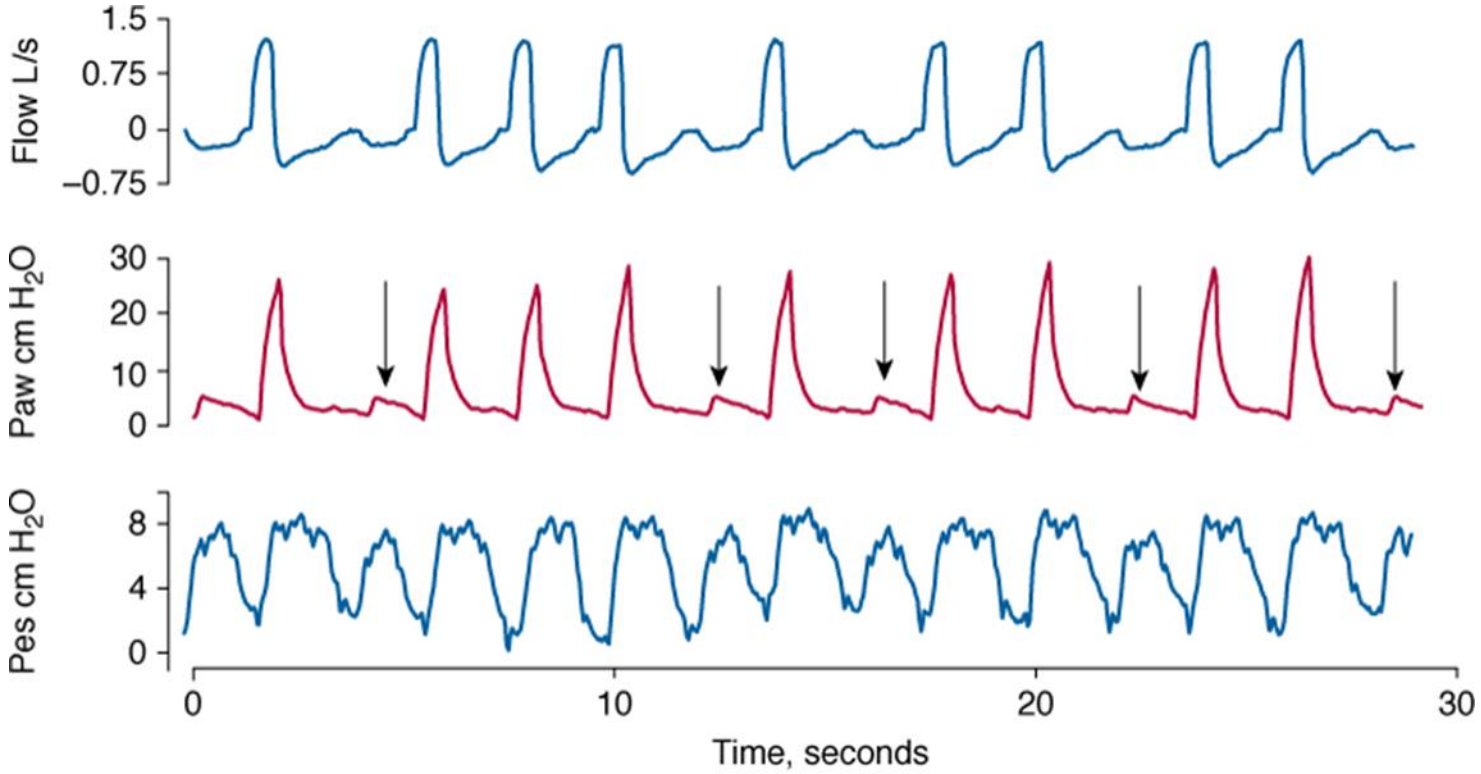
Guide Management

- Assess the response of drugs
- Optimize ventilator setting
  - Titrating FiO_2: SpO_2
  - Adjusting Pressure Support: V_T and RR
  - Setting PEEP
  - Assessing Patient Work of Breathing



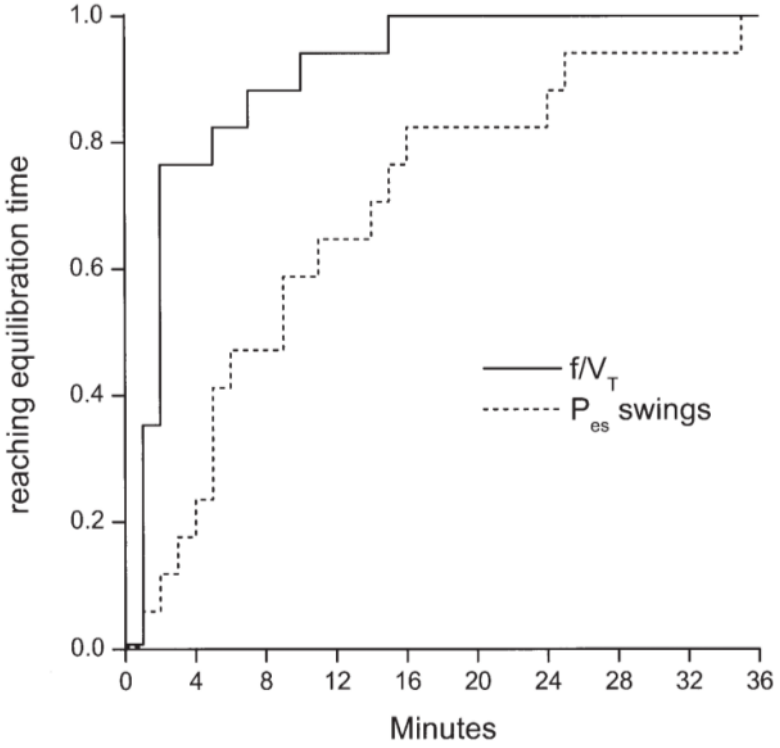
Assessing Patient Work of Breathing

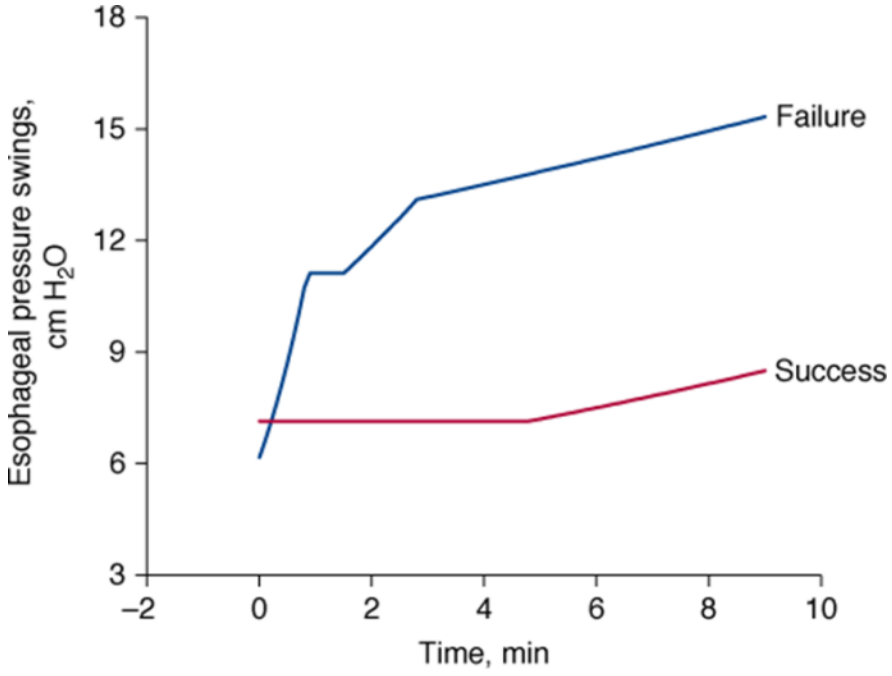
- Trigger failure



Source: Tobin MJ: *Principles and Practice of Mechanical Ventilation, 3rd Edition:* www.accessanesthesiology.com

Assessment of Trends



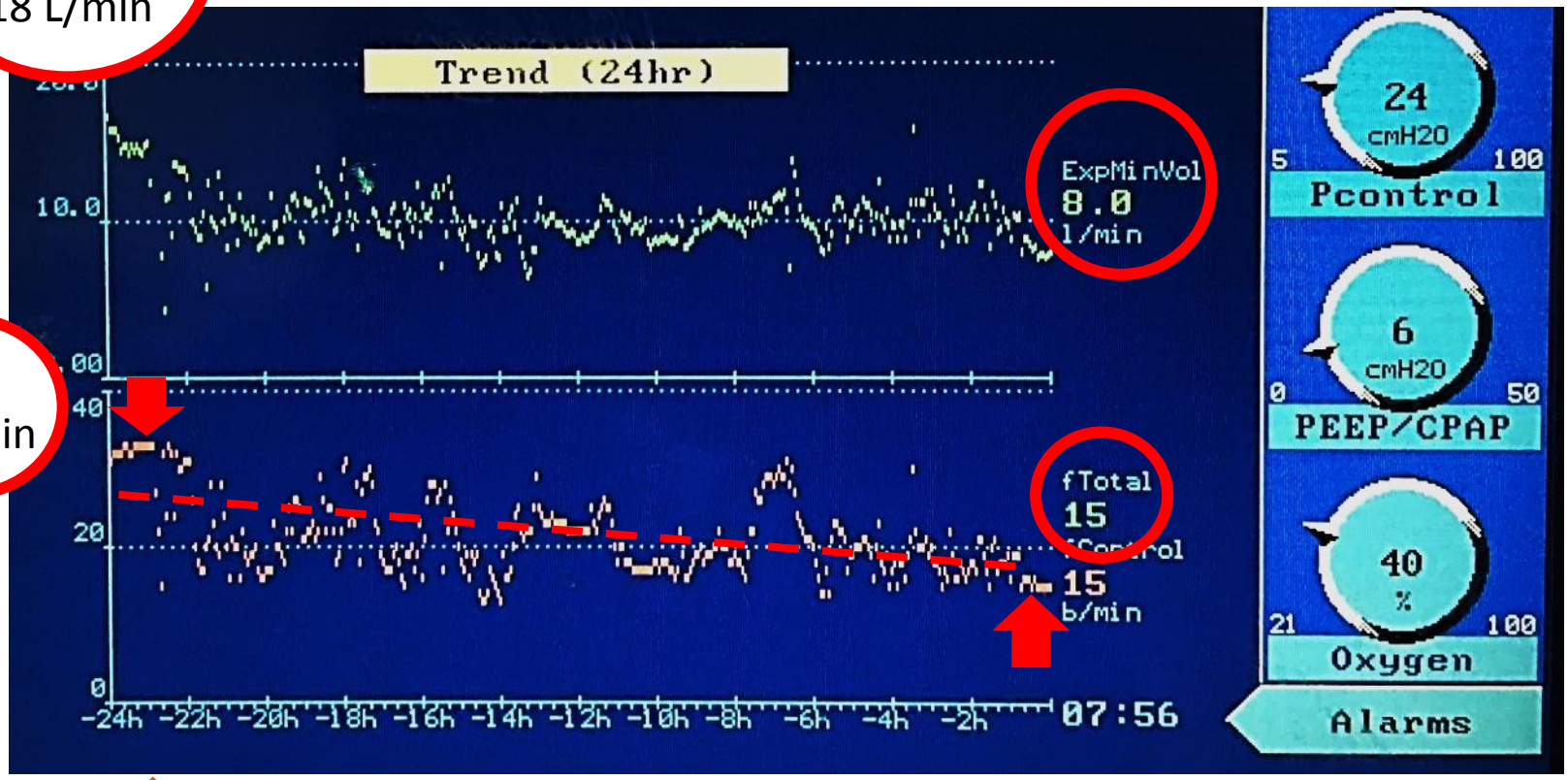


Change in Pes swings during weaning trials in weaning-failure and weaning-success patients.

Assessment of Trends

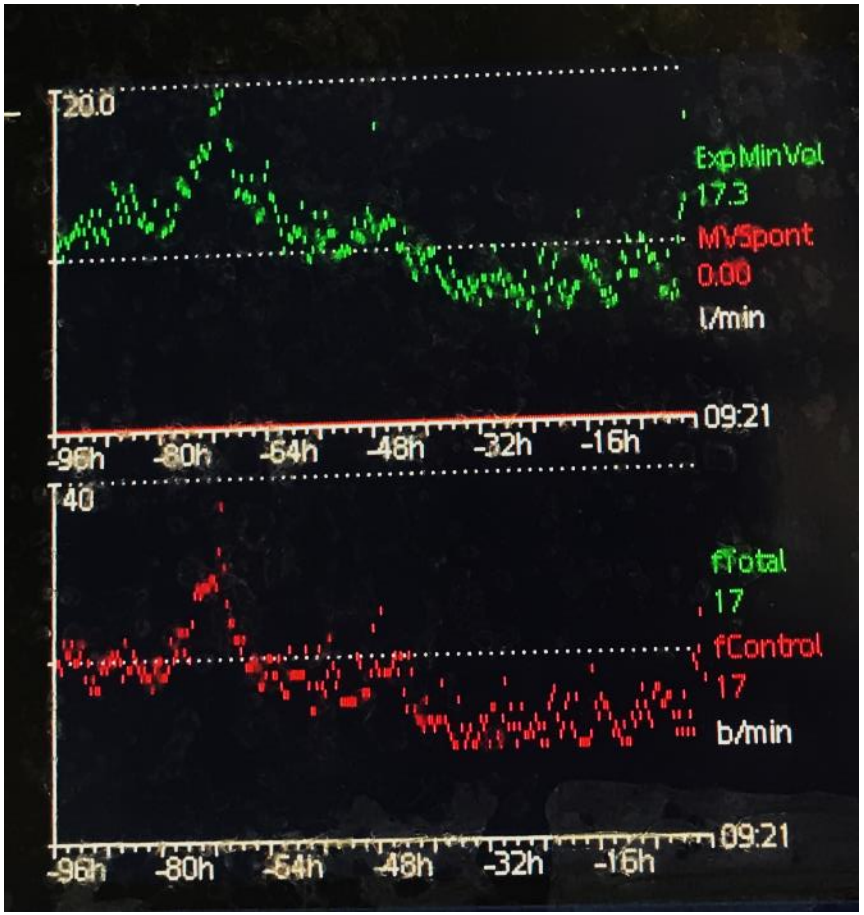
Minute Ventilation: 18 L/min

RR 35/min



Remove the infected Port-A

Assessment of Trends

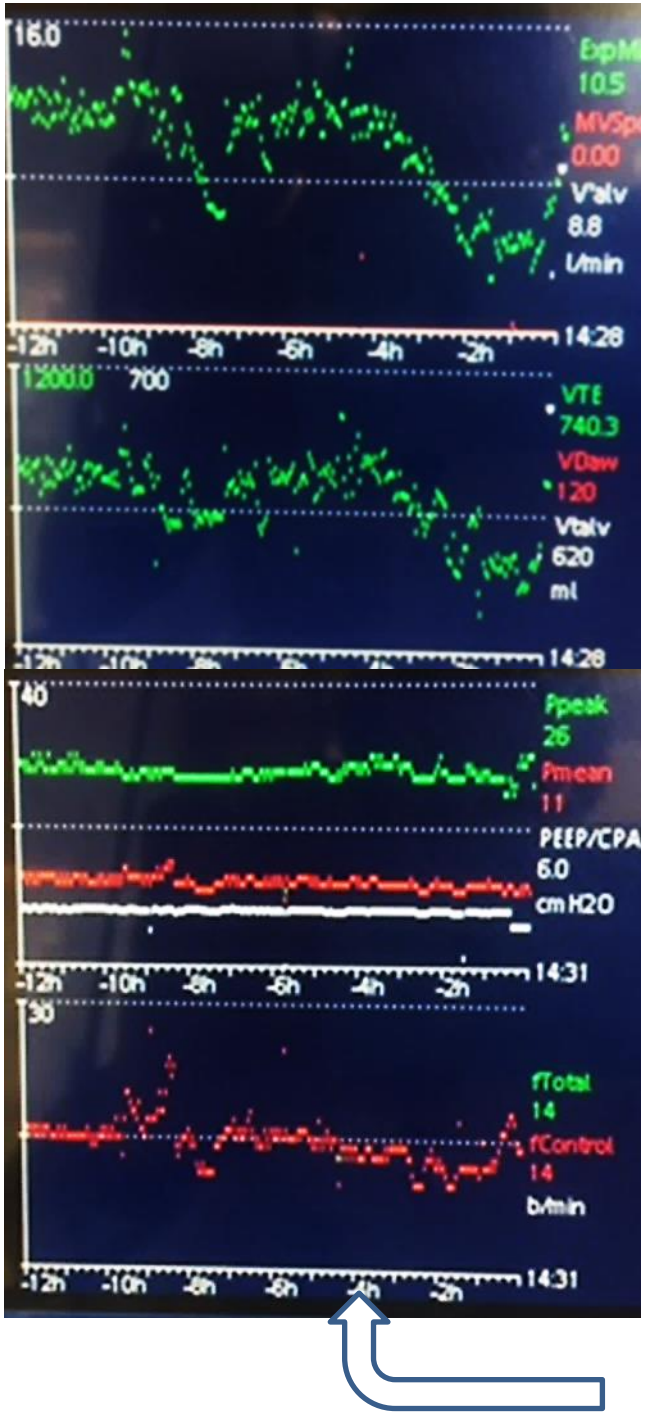


Acute onset of tachypnea and hypoxemia after initiation of parenteral nutrition: Possible ceftriaxone-calcium crystallization, led to a pulmonary-embolism-like reaction.

"Clinimix N17G35E Solution"

Ceftriaxone

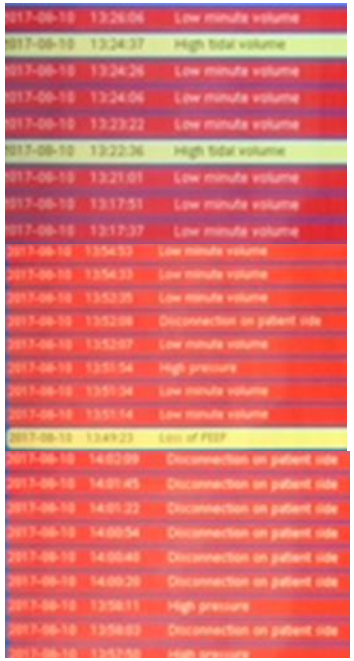
From a 3-way CVC



A case of ARDS

On call problem:

Sudden onset of BP drop

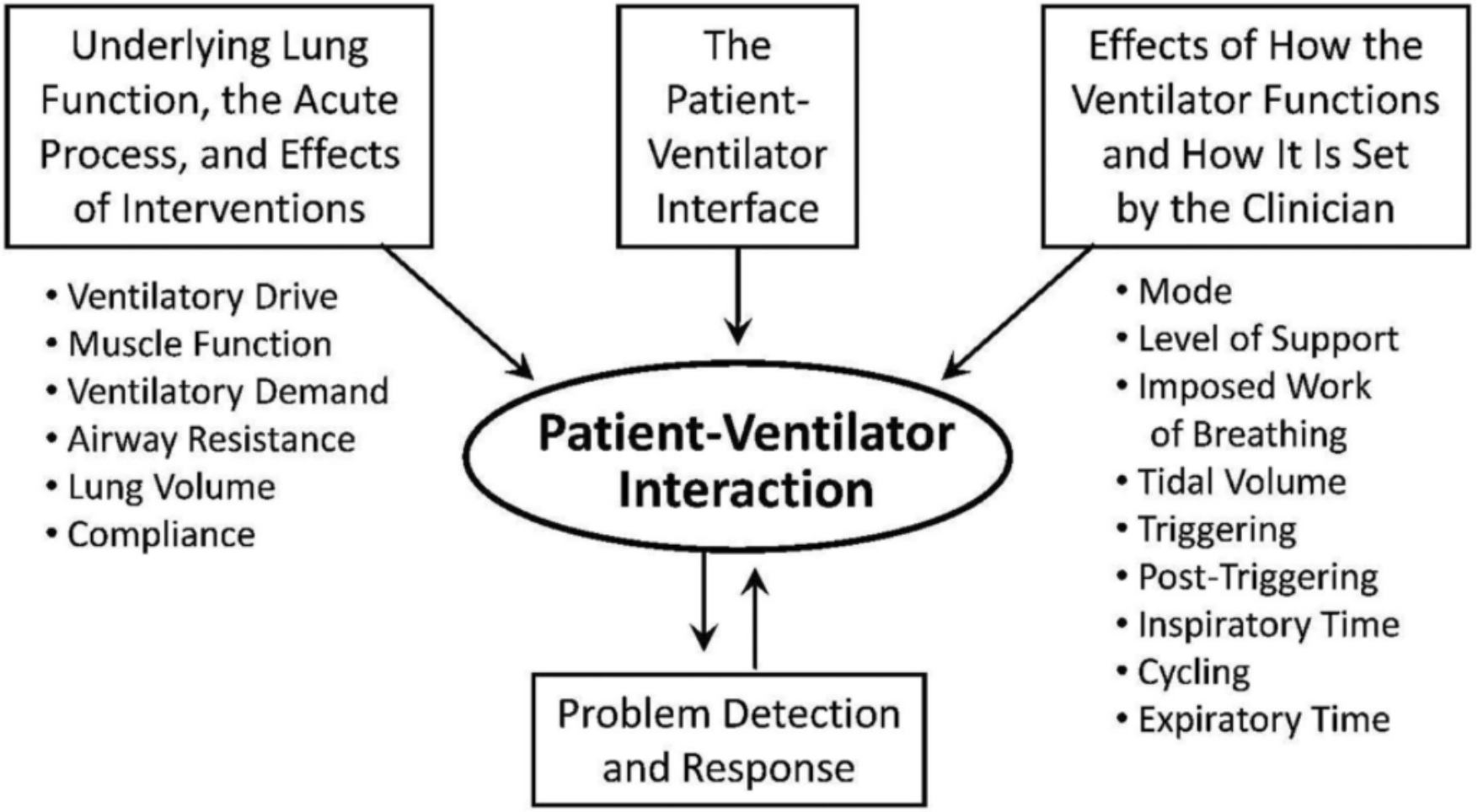


V_T and MV were decreasing from 4 hours ago

Part 2: Troubleshooting

- Patient-related problems
- Ventilator-related problems
- Patient-Ventilator interactions
  - Ventilatory muscle physiology
  - Patient-Ventilator Dyssynchrony (PVD)
- Other situation (cases)

Major reference:
Daniel Gilstrap *et al*, Patient-Ventilator interactions. AJRCCM 2013, 188: 1058-1068. Clin Chest Med 2016, 27:669-681
Susan P. Pilbeam, *et al*. Mechanical Ventilation: physiological and clinical applications. 5TH edition.



Respiratory Care 2011;56:214-228

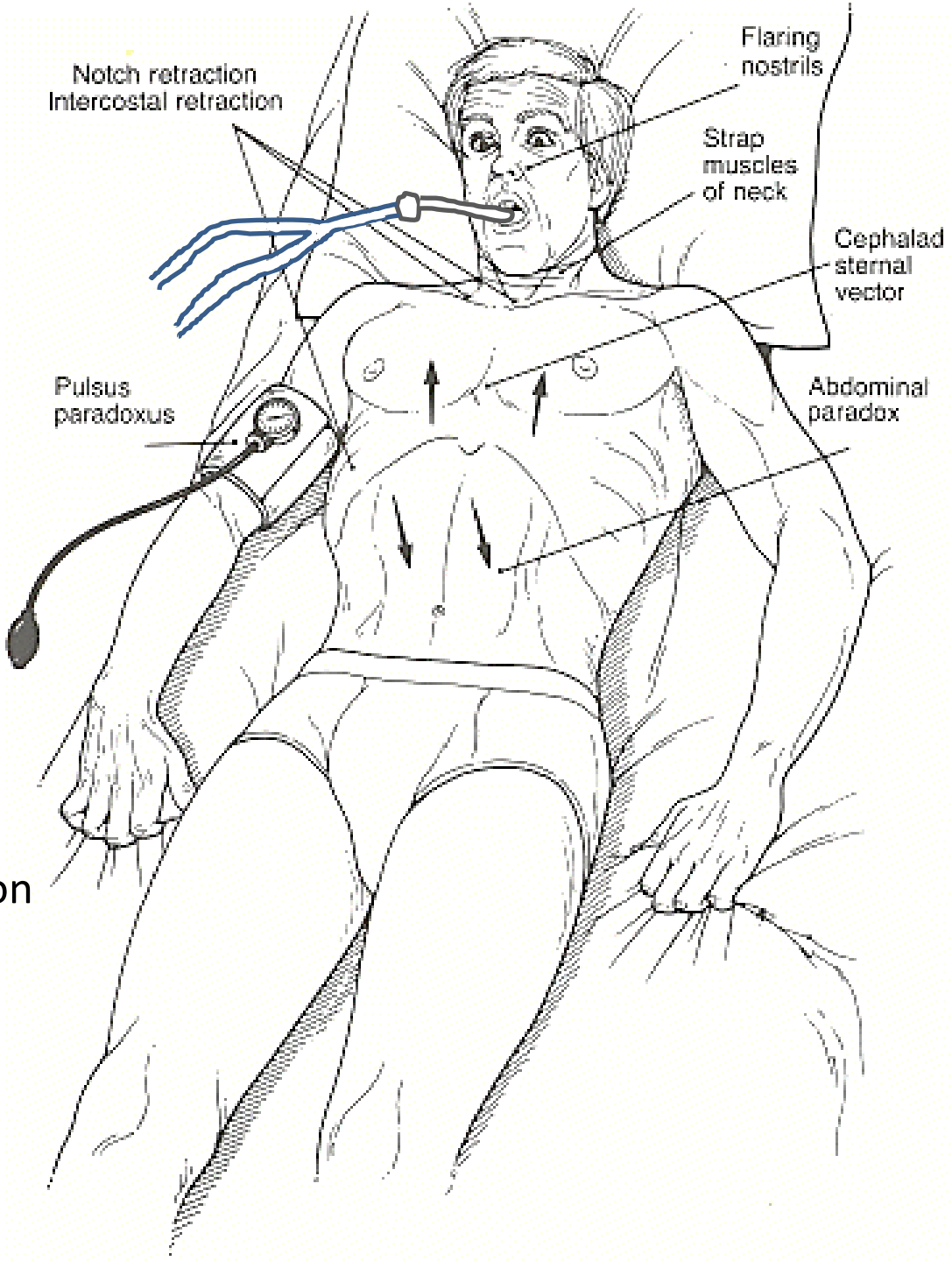
Patient-Related Problems

- Artificial airway obstruction
- Bronchospasm
- Secretions
- Pneumothorax
- Abdominal distension
- Pulmonary edema
- ARDS
- Pulmonary embolism
- Dynamic hyperinflation
- Metabolic acidosis
- Fulminant sepsis
- Agitation
- Abnormal respiratory drive
- Abnormal respiratory muscle strength /endurance
- ……

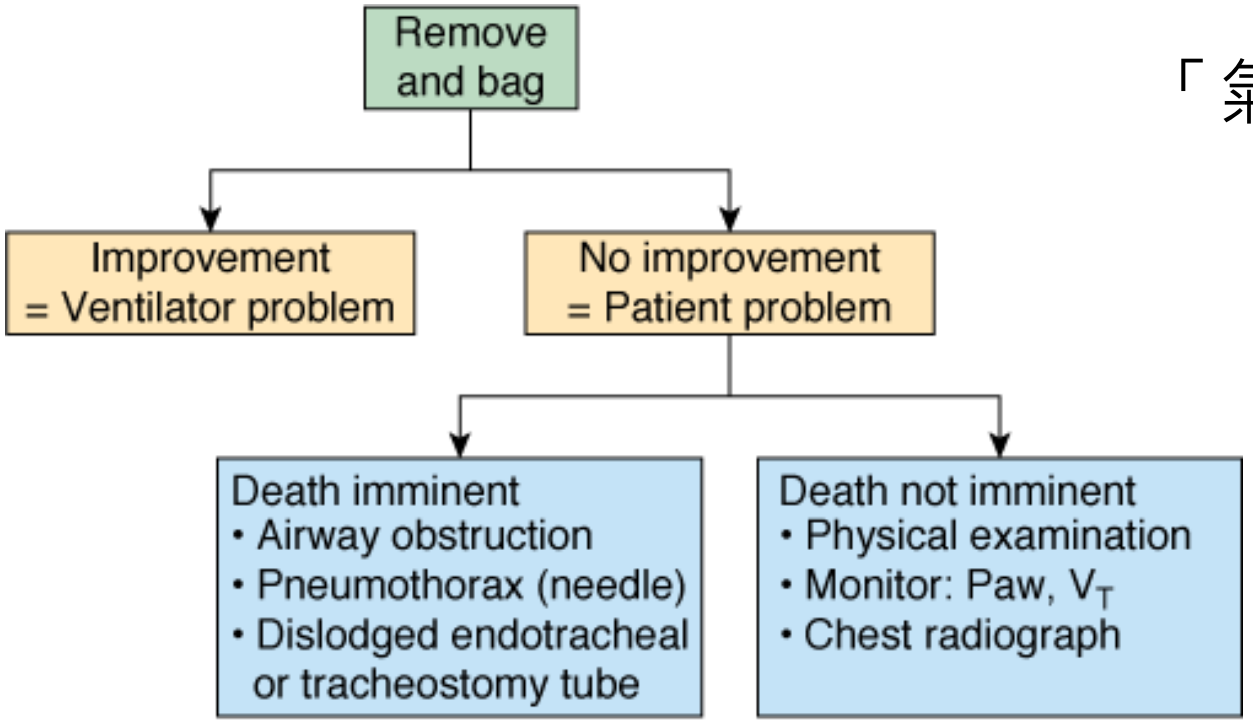
Pathophysiological Category of Respiratory Failure
Resistance
Compliance
Demand
O_2 exchange
CO_2 exchange
Neuromuscular

Physical Signs of Severe Respiratory Distress

- Change of consciousness
- Diaphoresis
- Tachypnea
- Tachycardia
- Anxiety
- Air hunger
- Accessory muscles
- Supraclavicular notch retraction



Management of Sudden Severe Distress in a Mechanical Ventilated Patient



「氣打不進去！」

- Fast PE
- Review alarm records
- Manually evaluate compliance and resistance through bagging

?

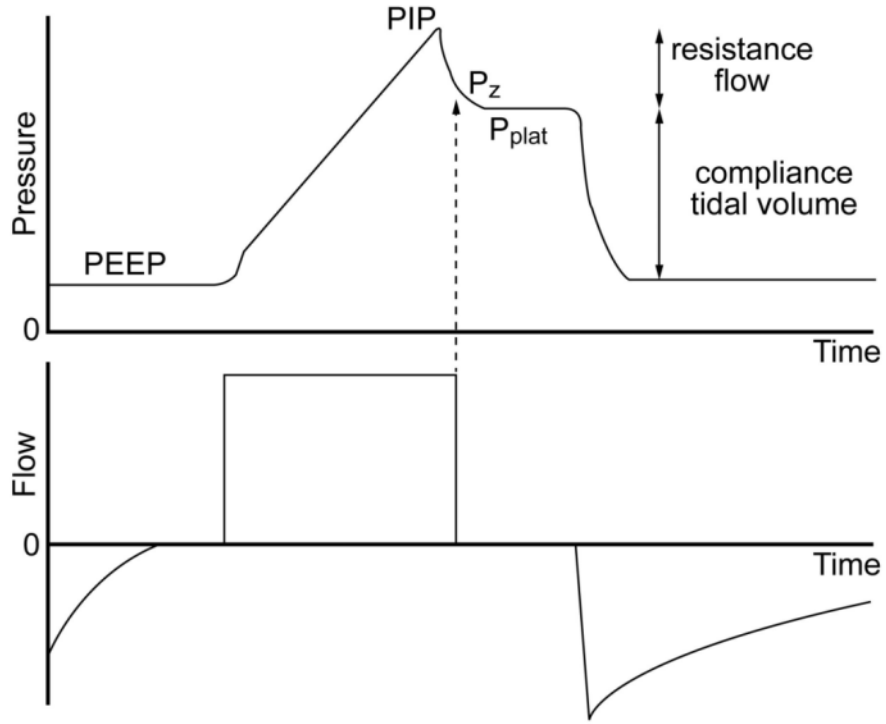
Can Ambu be Better than Ventilator?

DOPE:

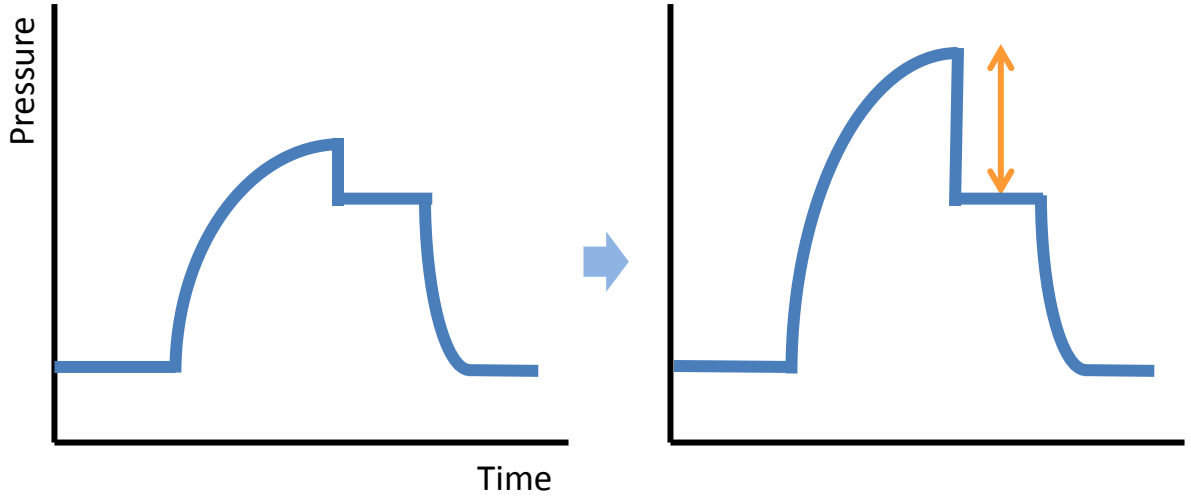
- **Dislodged tube**
- **O**bstructed ET tube
- **P**neumothorax
- **Equipment failure**

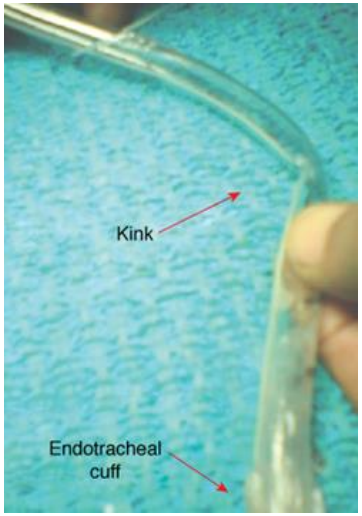
DOPE:

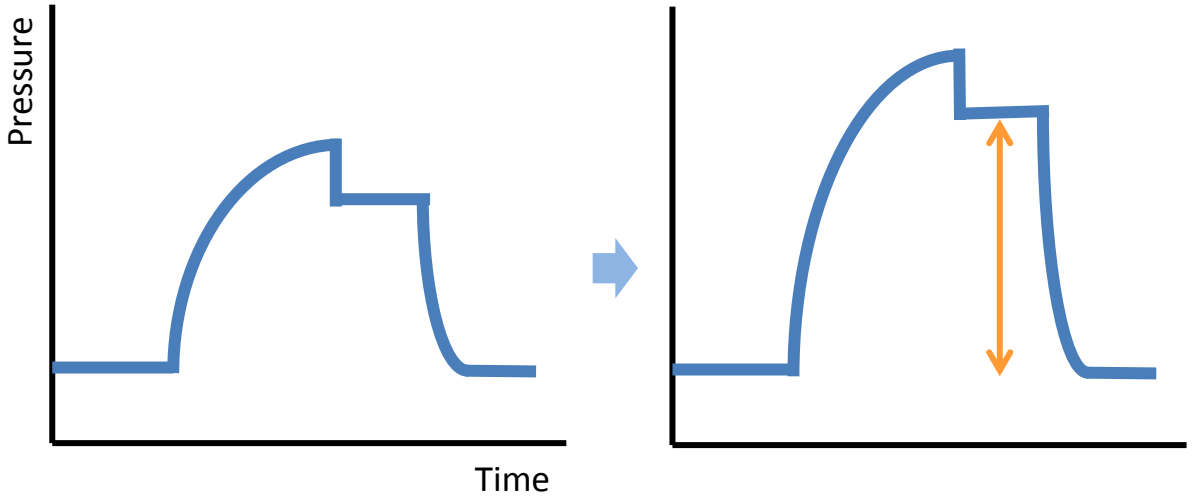
- Dislodged tube
- **Obstructed ET tube**
- **Pneumothorax**
- Equipment failure

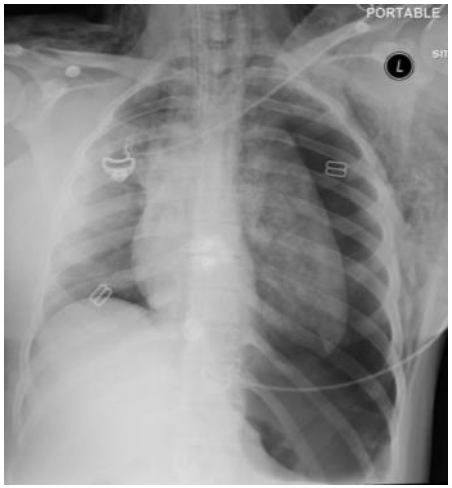


Volume Control Ventilation, Pressure-Time curve

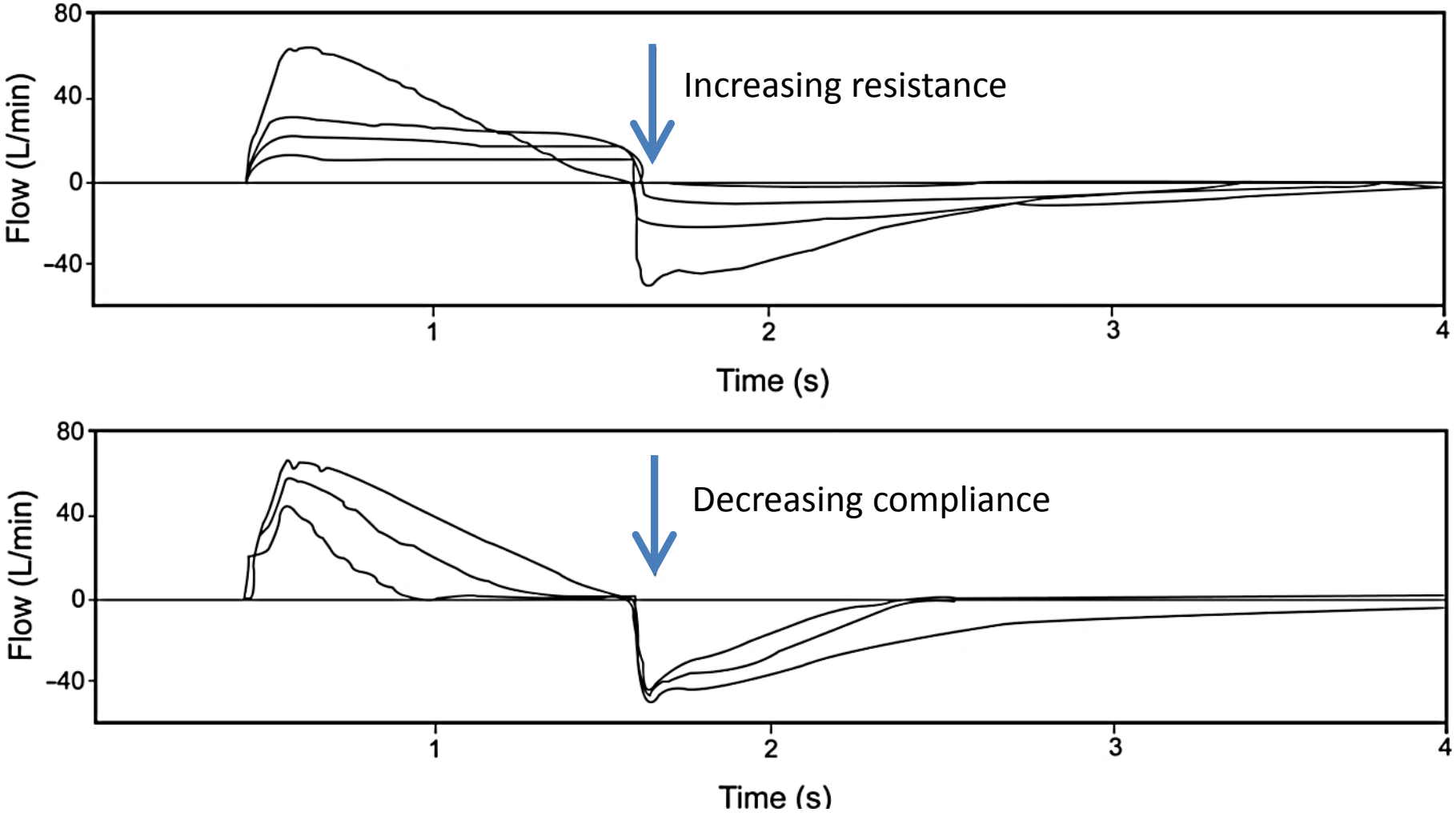








Pressure Control Ventilation, Flow-Time curve

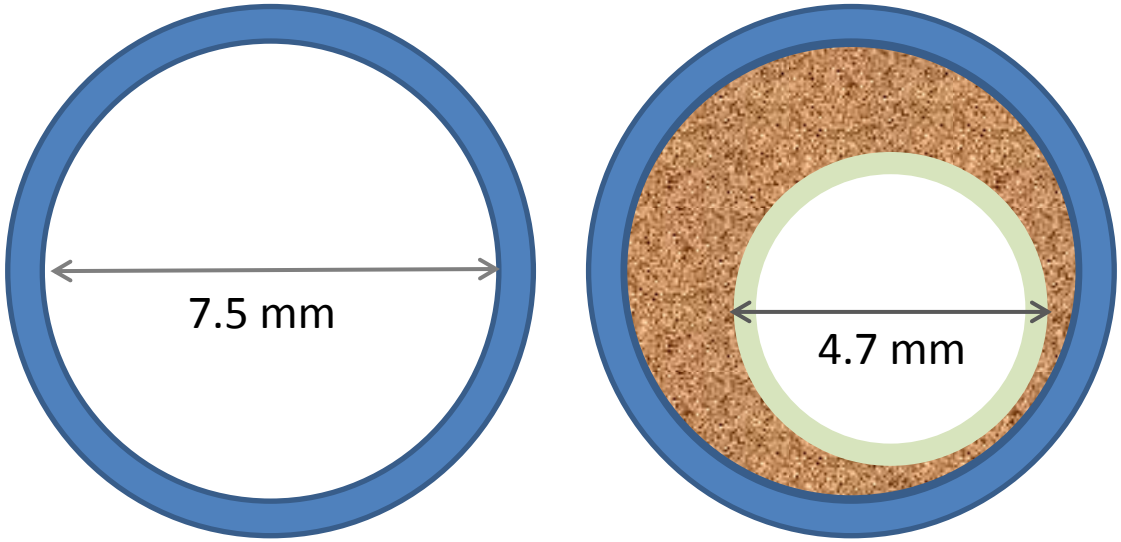


Respiratory Care. 2005;50:55-65
Respiratory Care. 2014;59:1773-1794

Obstructed ET tube

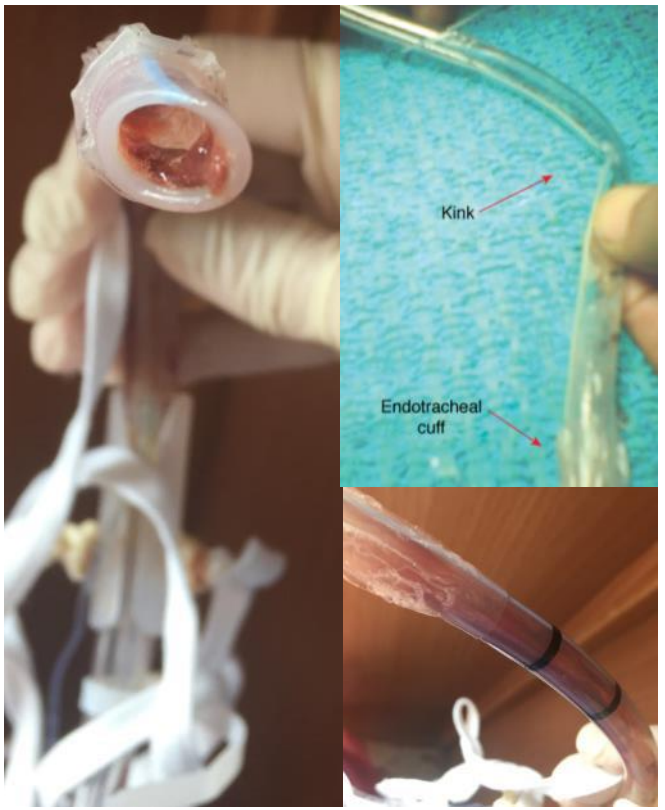
"Suctionable" ≠ No obstruction

$$R = \frac{8\eta l}{\pi r^4}$$

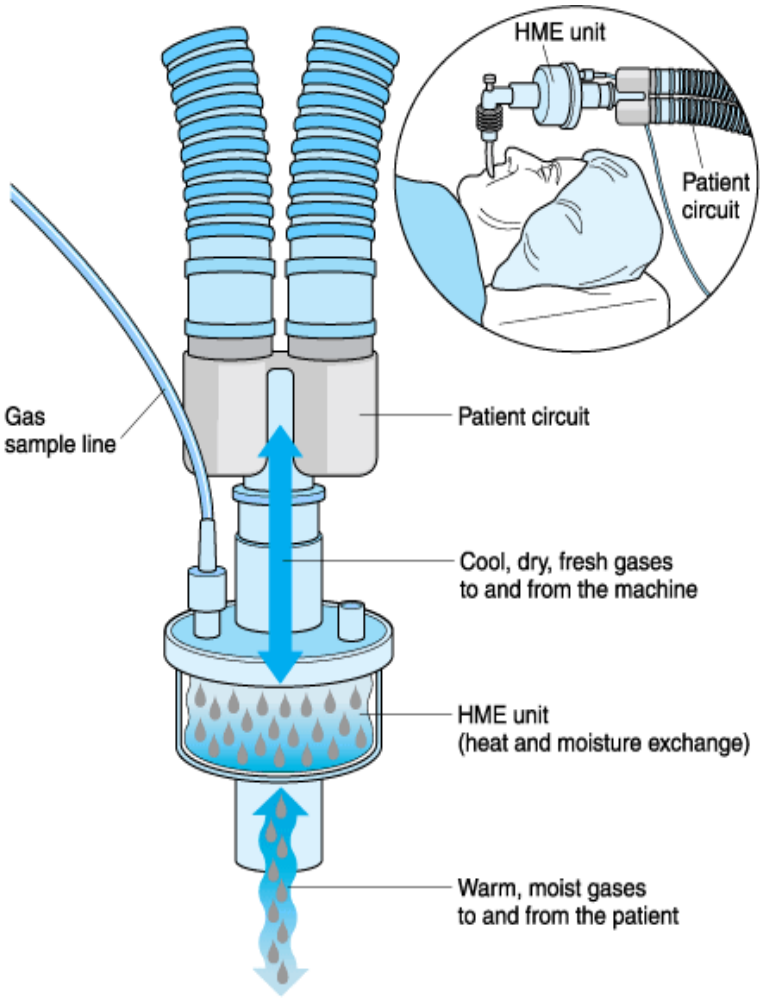


7.5 mm ETT

14 Fr. Suction tube



6.5X Resistance

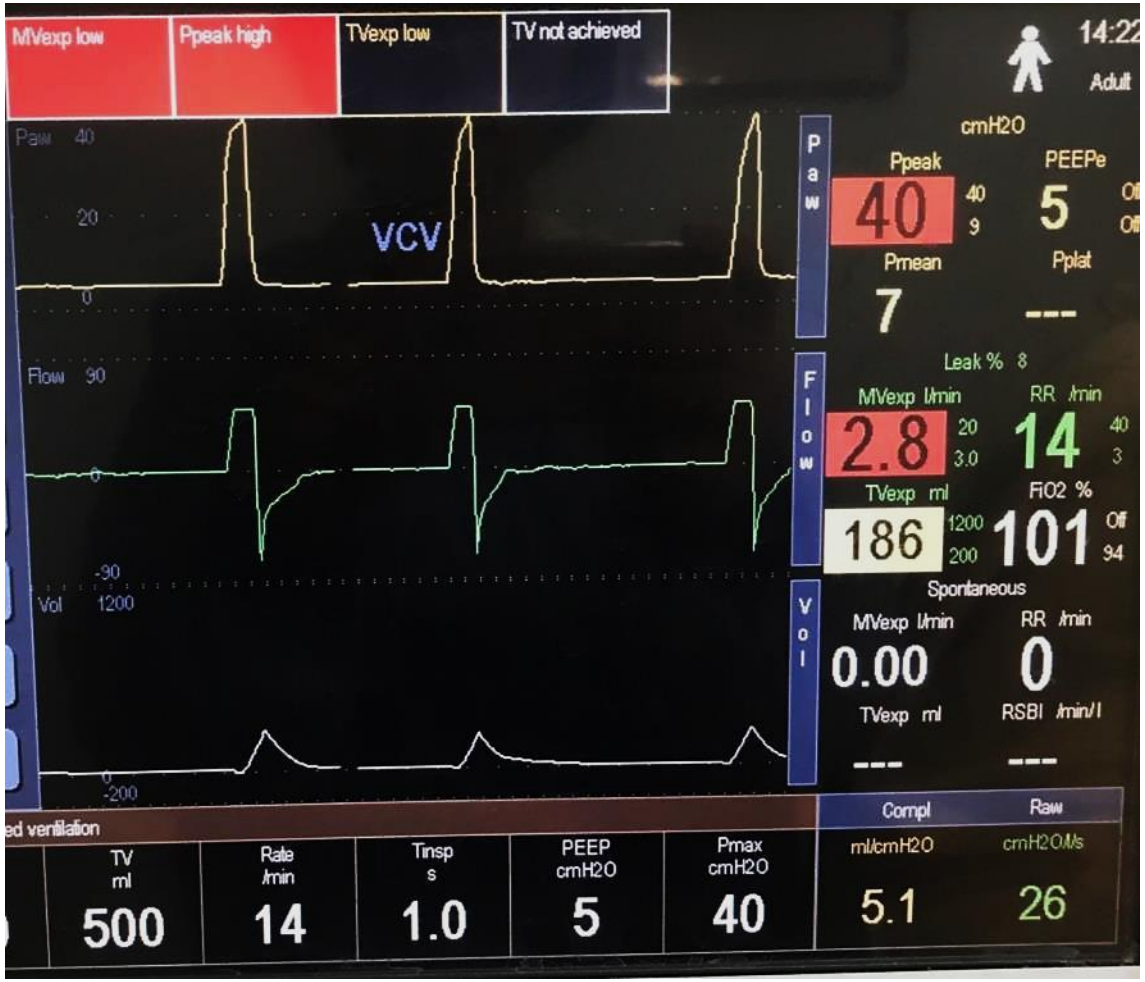


Contraindication of Using Heat and Moisture Exchanger

- **Frank bloody or thick, copious secretions.**
- **Prolonged use (> 48 ~ 72 hours)**
- **High minute ventilation (> 10 L/m)**
- Low V_T (e.g., ARDS, children)
- Increase resistance, dead space, $PaCO_2$, WOB
- Leak > 30% of V_T
- Hypothermia (< 32℃)

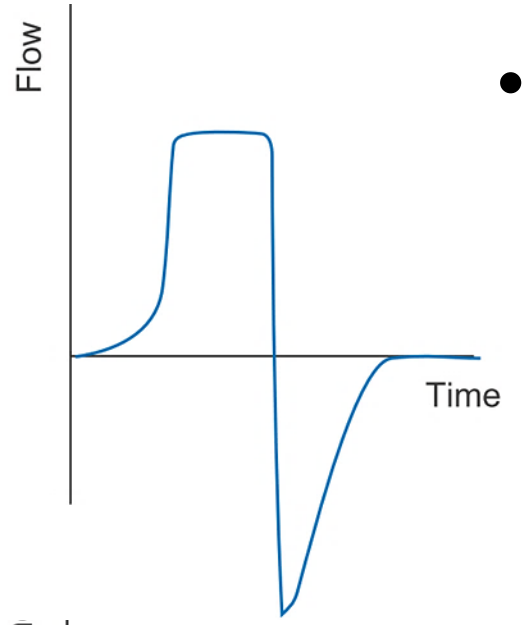
AARC Clinical Practice Guideline

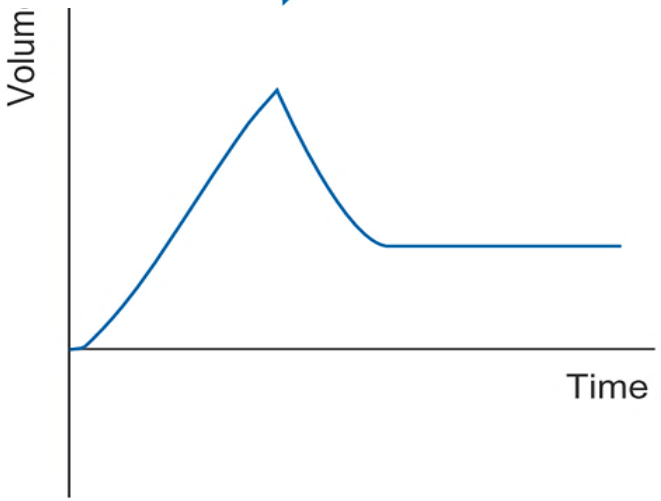
A Case of Microscopic Polyangiitis



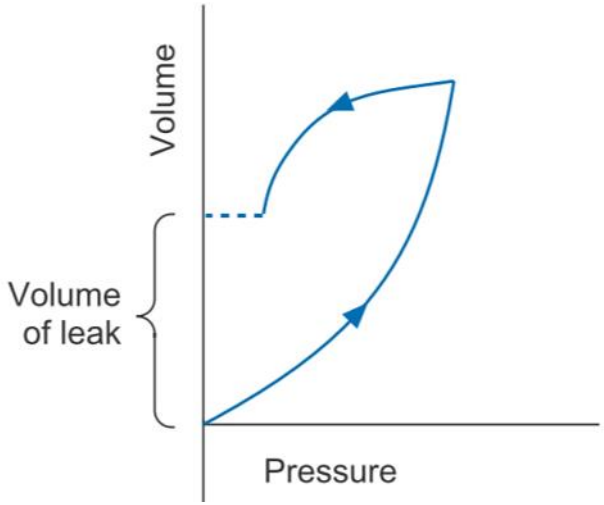
Ventilator Related Problems

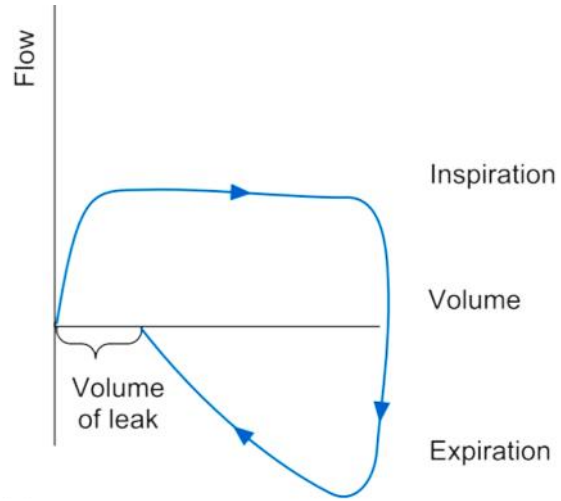
- **System leak**



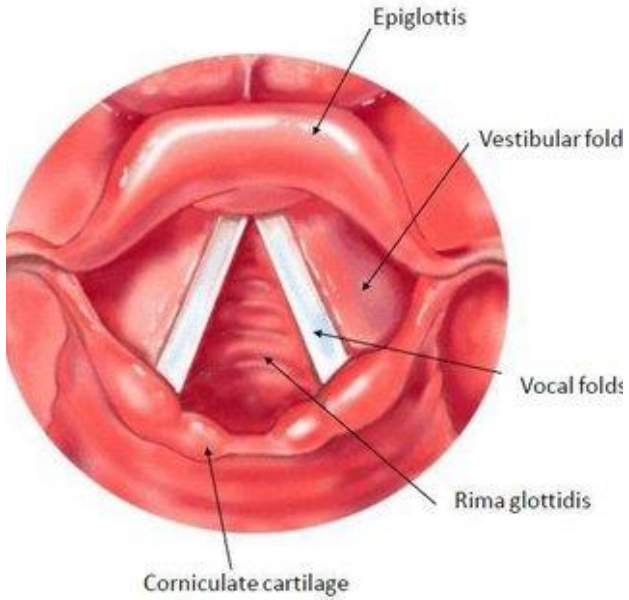


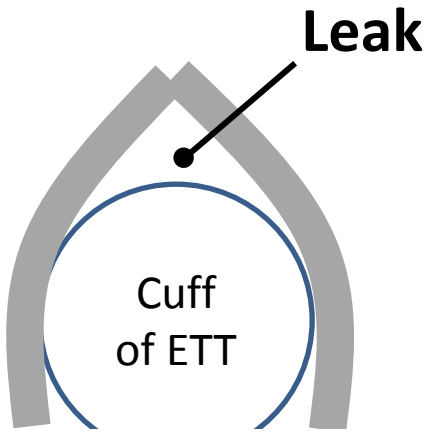
F-T curve	P-V loop
V-T curve	F-V loop

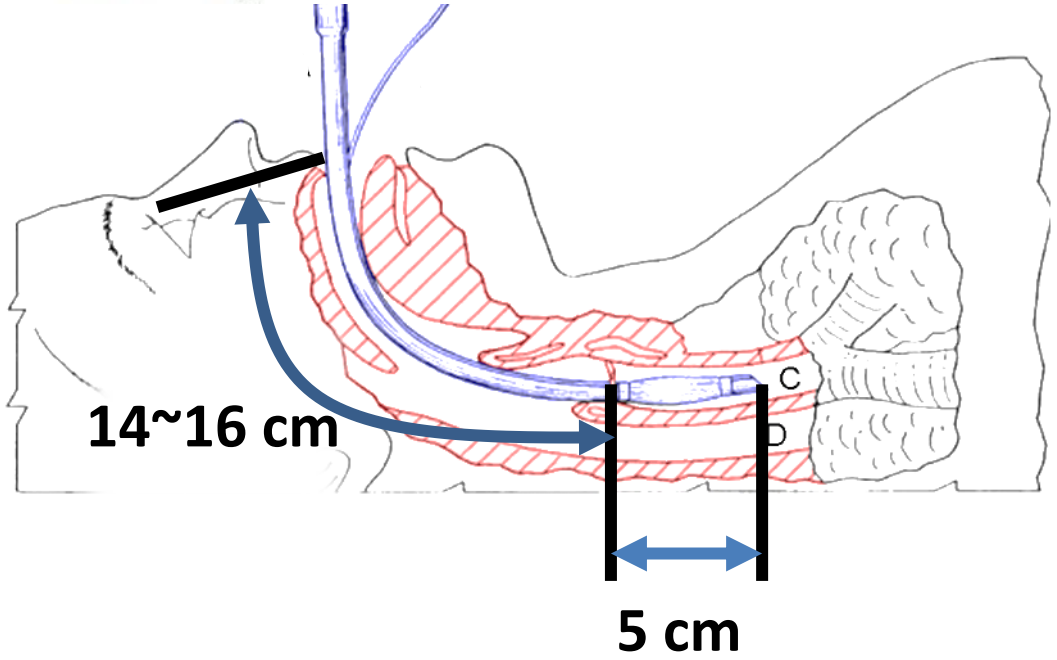




不是cuff打飽就好

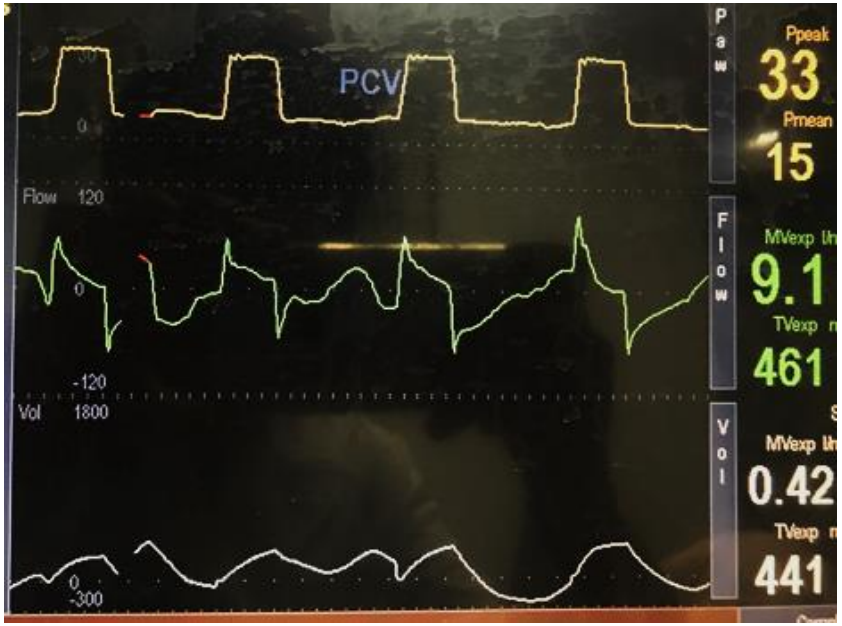

Epiglottis
Vestibular fold
Vocal folds
Rima glottidis
Corniculate cartilage

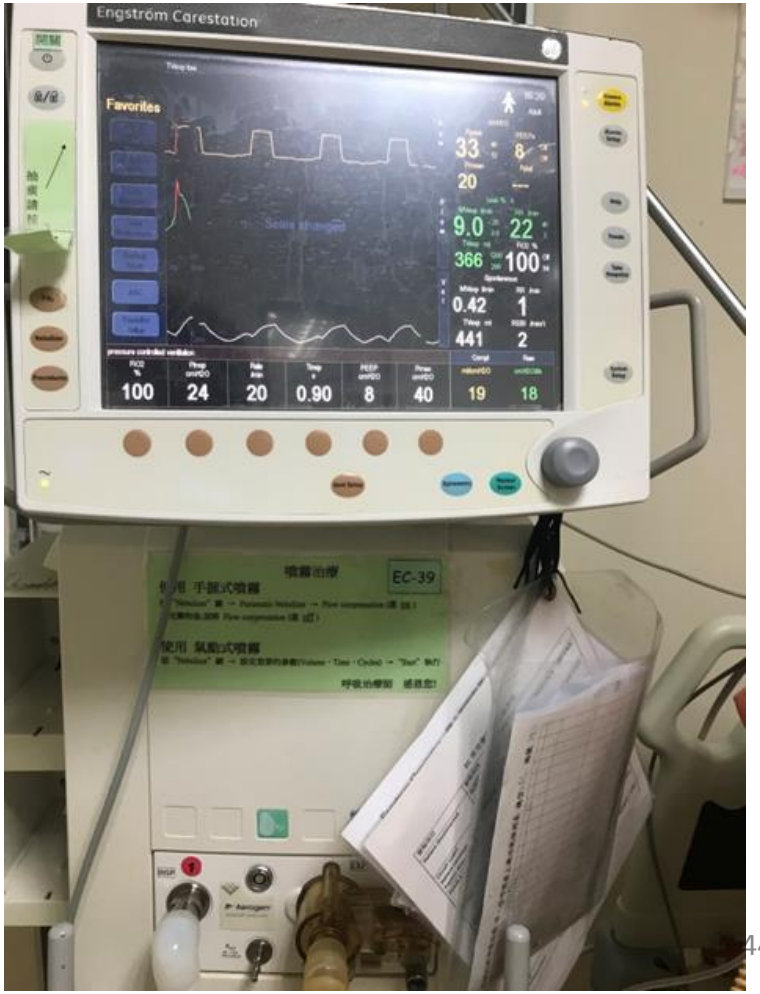

Leak
Cuff
of ETT


14~16 cm
C
D
5 cm

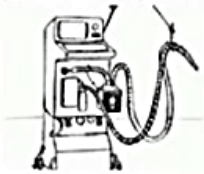
Ventilator Related Problems

- **Circuit malfunction or disconnection**





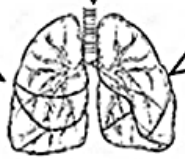
Interaction between Organs and Ventilator Involved in Dyssynchrony



VENTILATOR
Alarms ++
Inappropriate delivered ventilation

BRAIN
Dyspnea
Agitation
Sleep disruption
Excessive (deep) sedation
Delirium

DIAPHRAGM
Disuse= atrophy
Excessive work= injury, ↗ O_2 consumption
Eccentric contraction = injury



LUNG
Loss of protective ventilation
= Local (and systemic) inflammation

Difficult weaning
Prolonged mechanical ventilation
Decreased survival

Crit Care Clin 2018;34:325–341

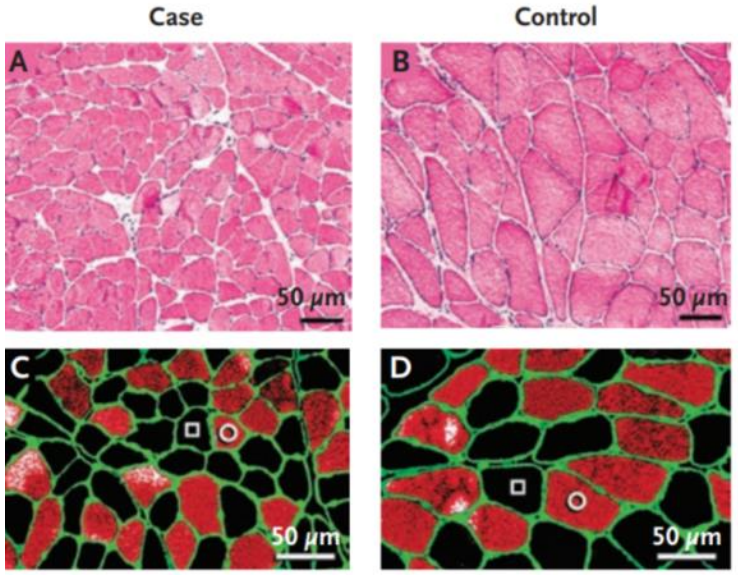
Patient-Ventilator Interaction

- **Ventilatory muscle physiology**
- Patient-Ventilator Dyssynchrony (PVD)
  - Triggering
  - Flow / Pressure
  - Cycling

Goal of Mechanical Ventilation

- Reduce work of breathing (WOB)
  - Support cardiac work
- Improve gas exchange and oxygenation
- Improve patient comfort

Silent Ventilatory Muscle



- Prolonged ventilator
- Prolonged post-ICU disability

Dyssynchrony

- Overload muscles
- Dyspnea, fighting, disrupted sleep
- Dynamic hyperinflation
- Ventilator-induced lung injury
- Excessive sedation administration

NEJM 2008; 358:1327-1335

$$Ptot = Pel + Pres + P_{PEEPi}$$

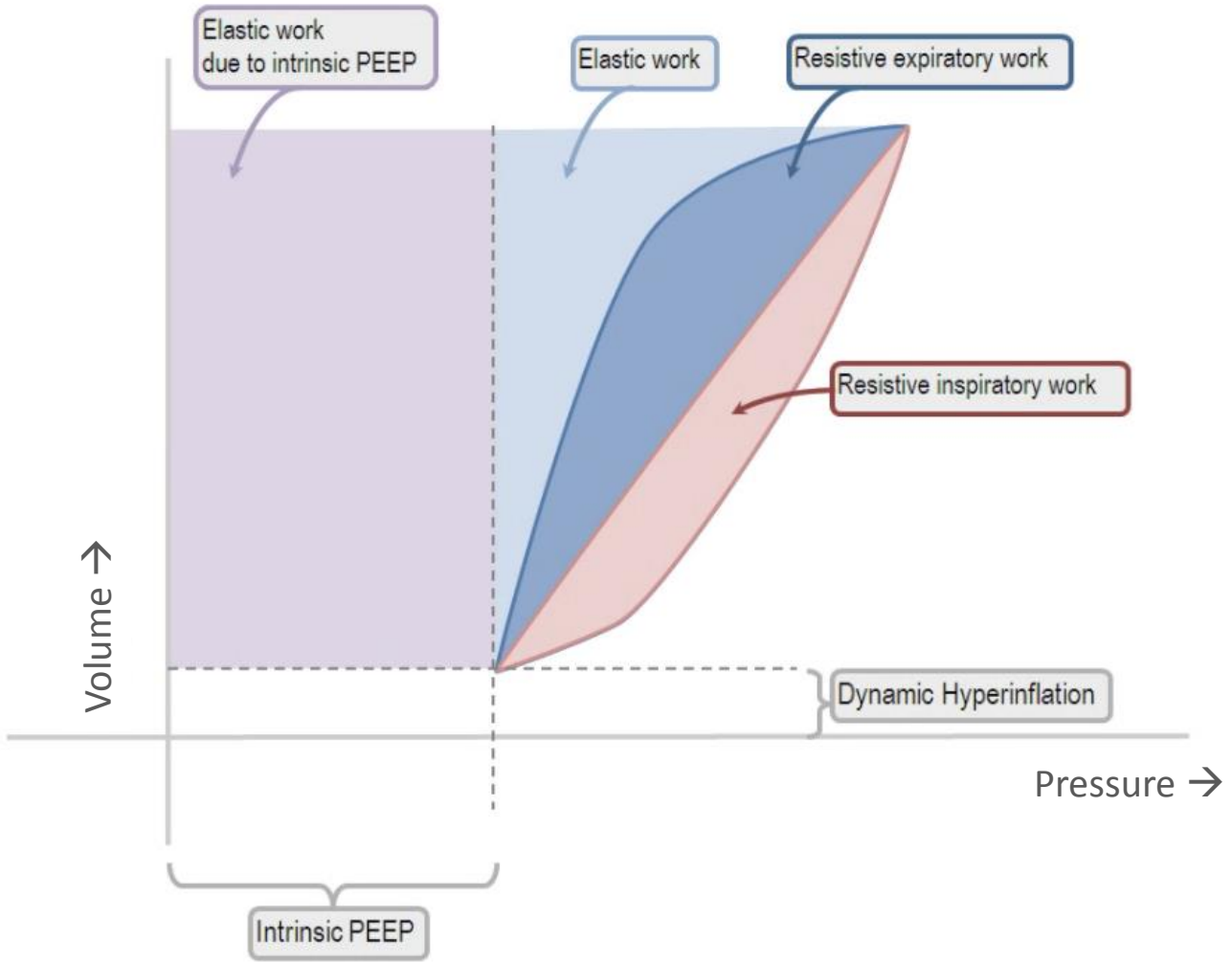
$$= (\Delta V / Crs) + (R \times V') + P_{PEEPi}$$

$$Ptot = Pmus + Pvent$$

Pel: the pressure to overcome the loads of respiratory system elastic recoil
Pres: the pressure to overcome the loads of airway resistance
P_{PEEPi}: the pressure to overcome the loads of auto-PEEP
V': given flow
ΔV: volume change
Crs: respiratory system compliance
R: airway resistance

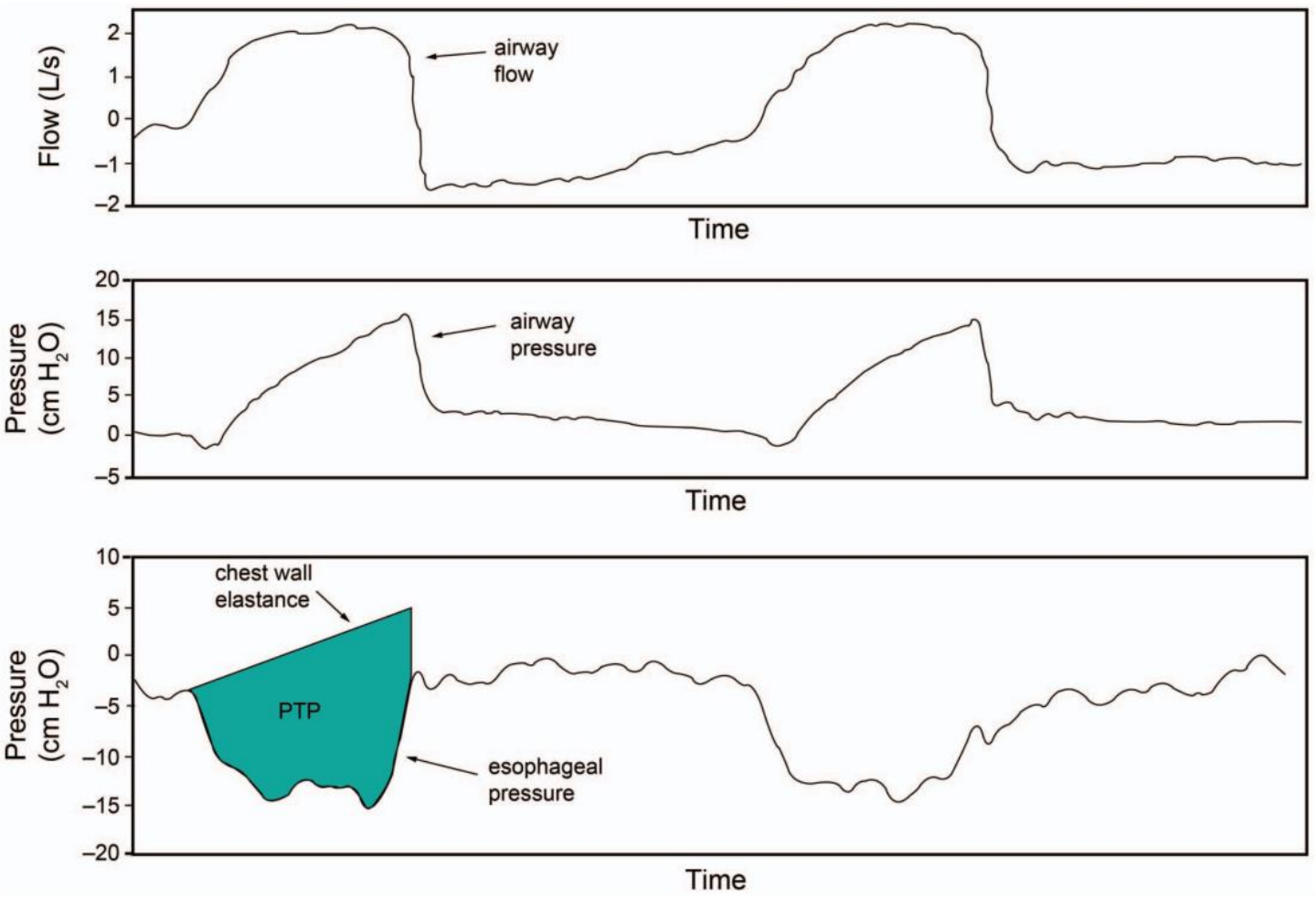
Mechanical Loads:
Work (W)

P · dV



Mechanical Loads:
Pressure–time product (PTP)

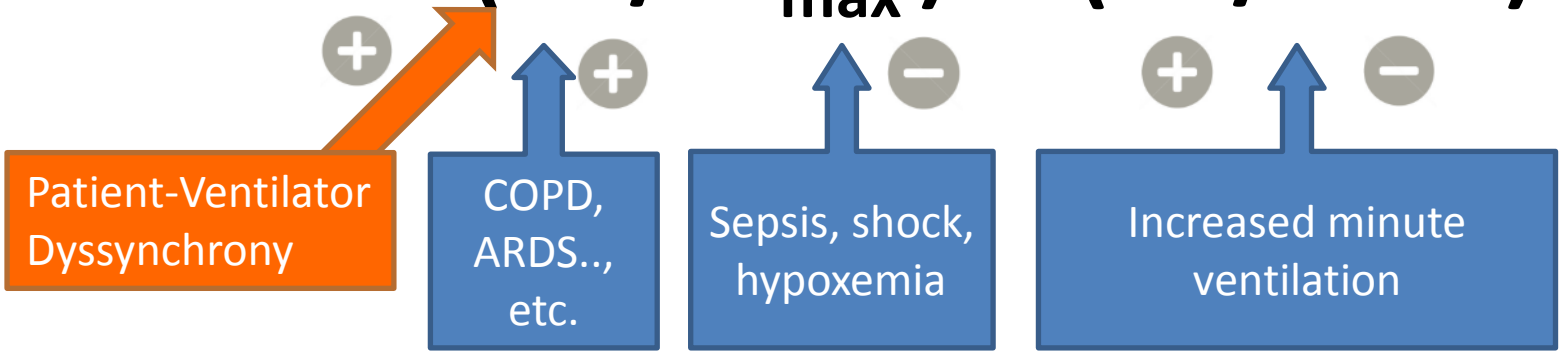
P · dT



Respiratory Care. 2014;59:1773-1794

Pressure-Time Index (PTI)

$$PTI = (Pi / Pi_{max}) \times (Ti / Ttot)$$

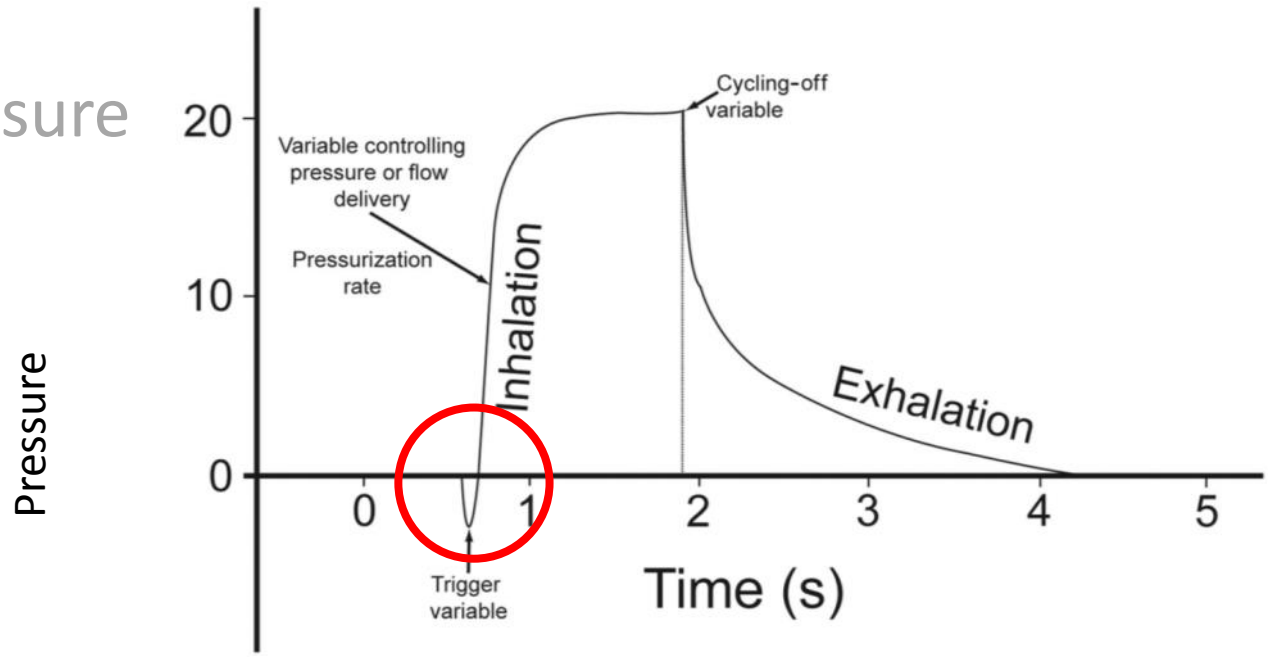


- Normal: < 0.05
- Exercise: < 0.1
- PTI > 0.15 for the diaphragm and > 0.3 for rib cage muscles are related to the development of ventilatory muscle failure.

AJRCCM 2004;170:626-632
J Appl Physio 1982;53:1190-1195

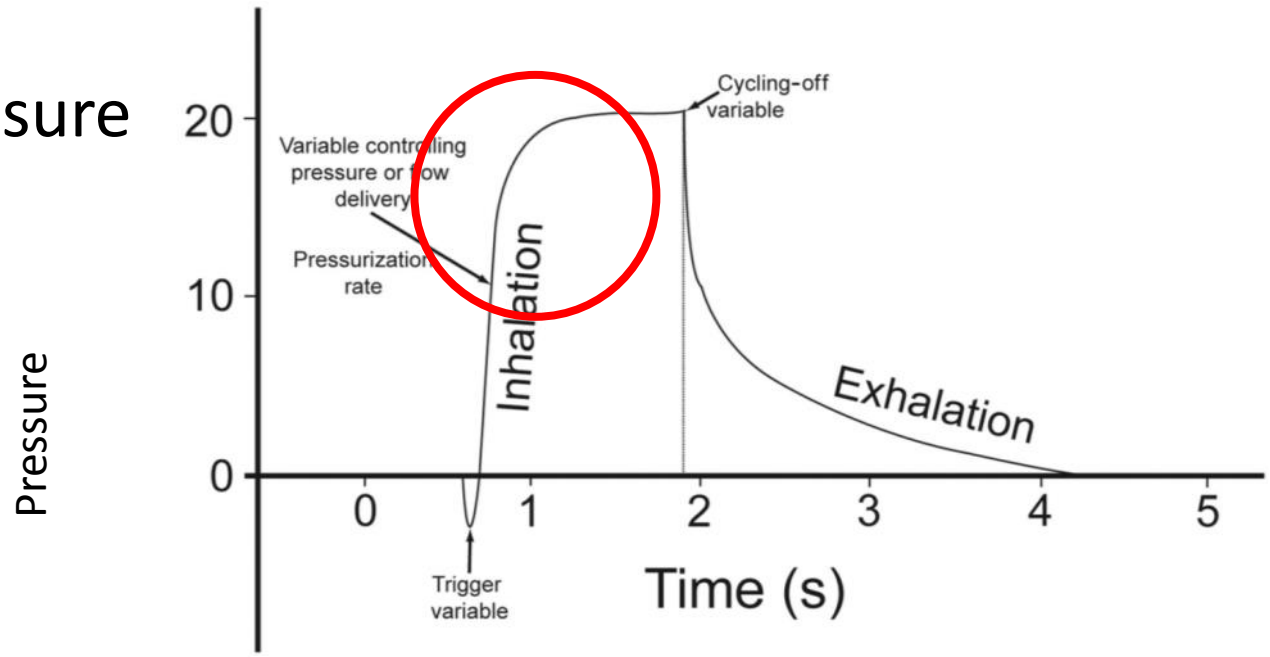
Patient-Ventilator Interaction

- Ventilatory muscle physiology
- **Patient-Ventilator Dyssynchrony (PVD)**
  - Triggering
  - Flow / Pressure
  - Cycling



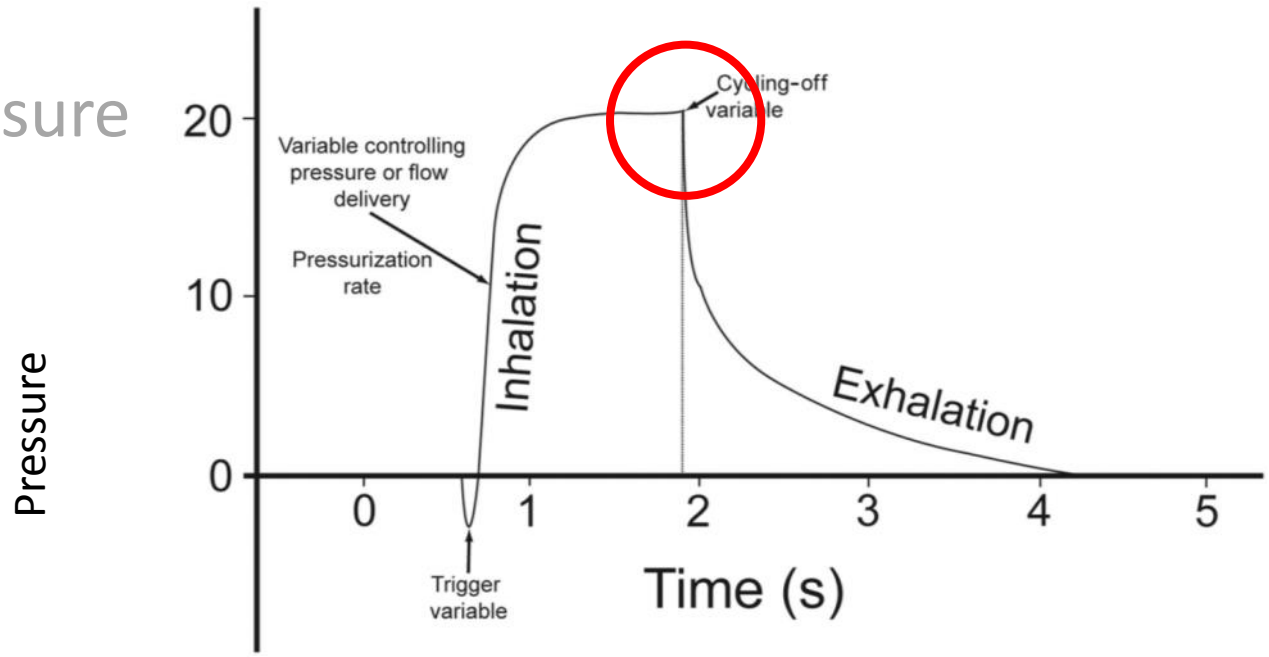
Patient-Ventilator Interaction

- Ventilatory muscle physiology
- Patient-Ventilator Dyssynchrony (PVD)
  - Triggering
  - Flow / Pressure
  - Cycling



Patient-Ventilator Interaction

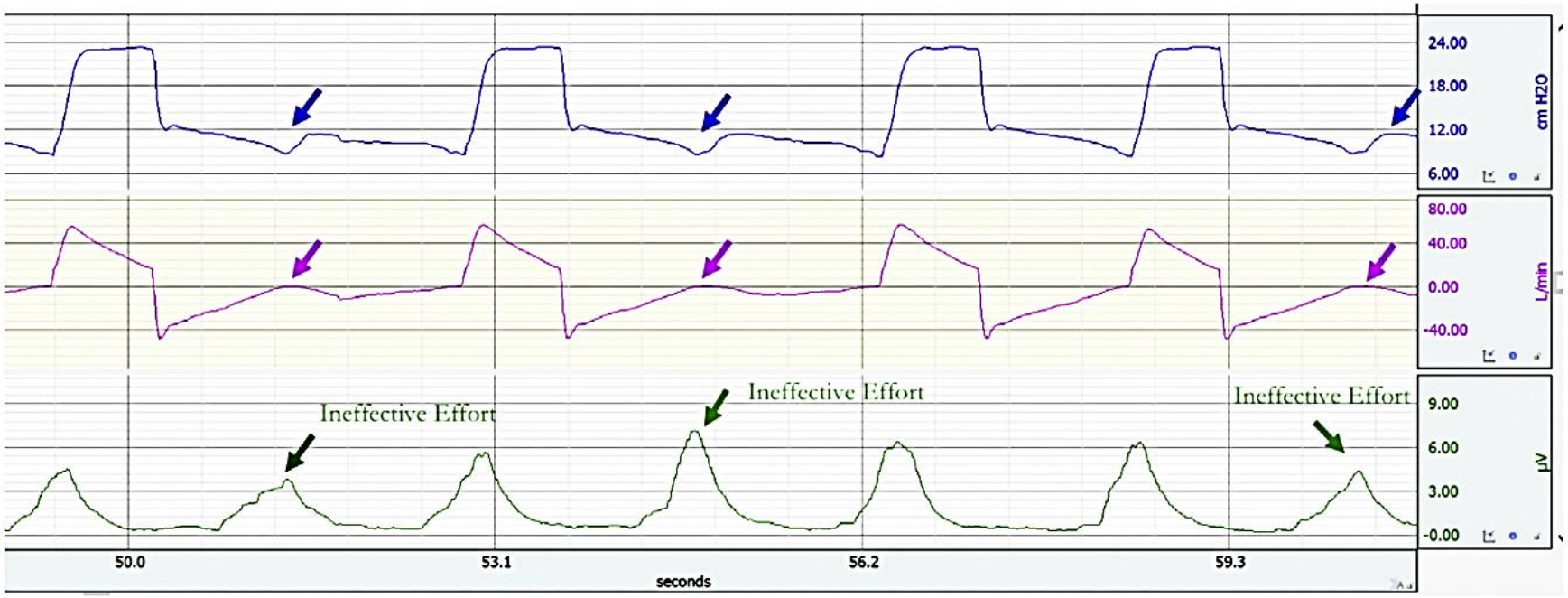
- Ventilatory muscle physiology
- Patient-Ventilator Dyssynchrony (PVD)
  - Triggering
  - Flow / Pressure
  - Cycling



Trigger Dyssynchrony

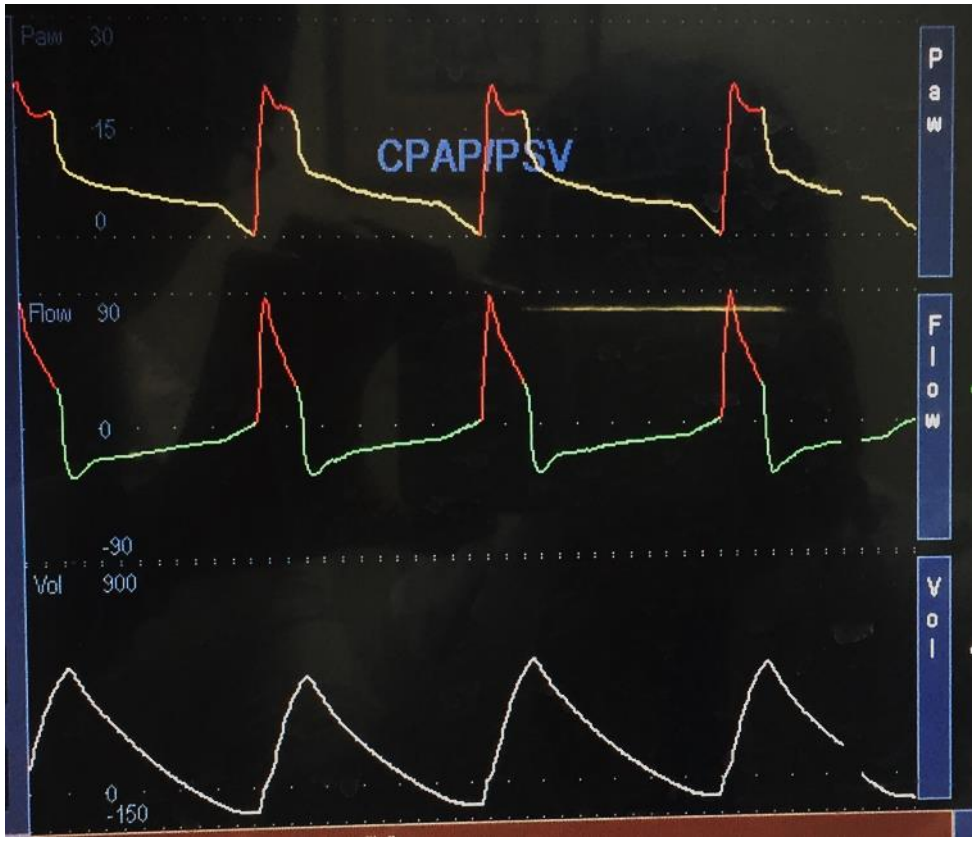
- Delayed/missed triggers
  - Intensive and/or unresponsive systems
  - Intrinsic PEEP (PEEPi)
- Extra-triggering
  - Auto-triggering
  - Reverse triggering (entrainment)
  - Double triggering (premature cycling of patient-triggered breath)

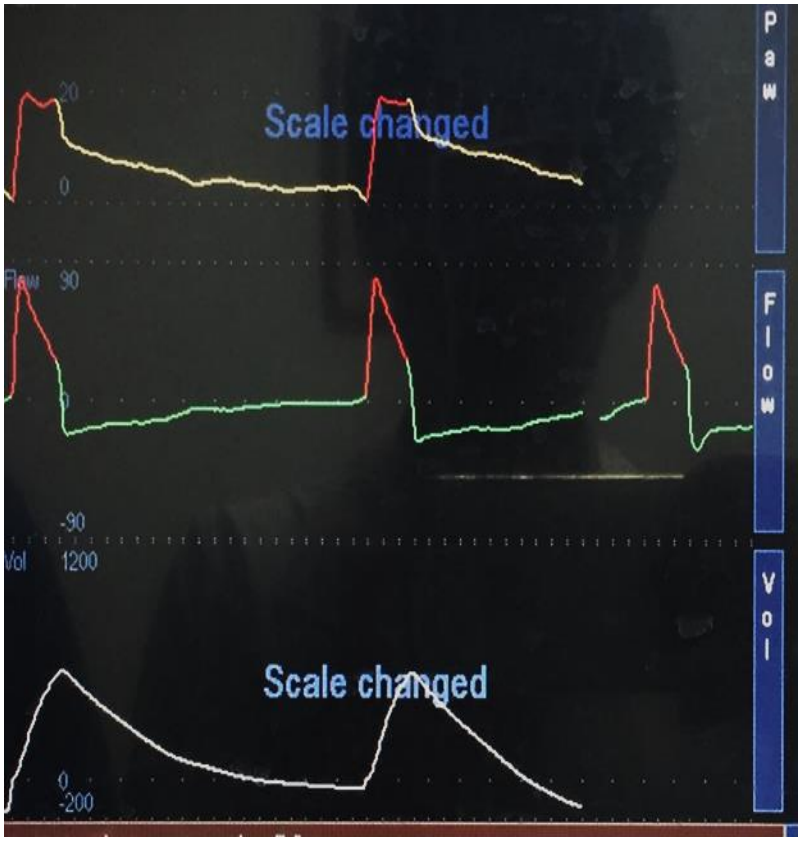
Triggering:
Intensive and/or unresponsive systems



Solution: Adjust flow sensitivity: -3 L/min → -1.5 L/min

Crit Care Clin 2018;34:325–341



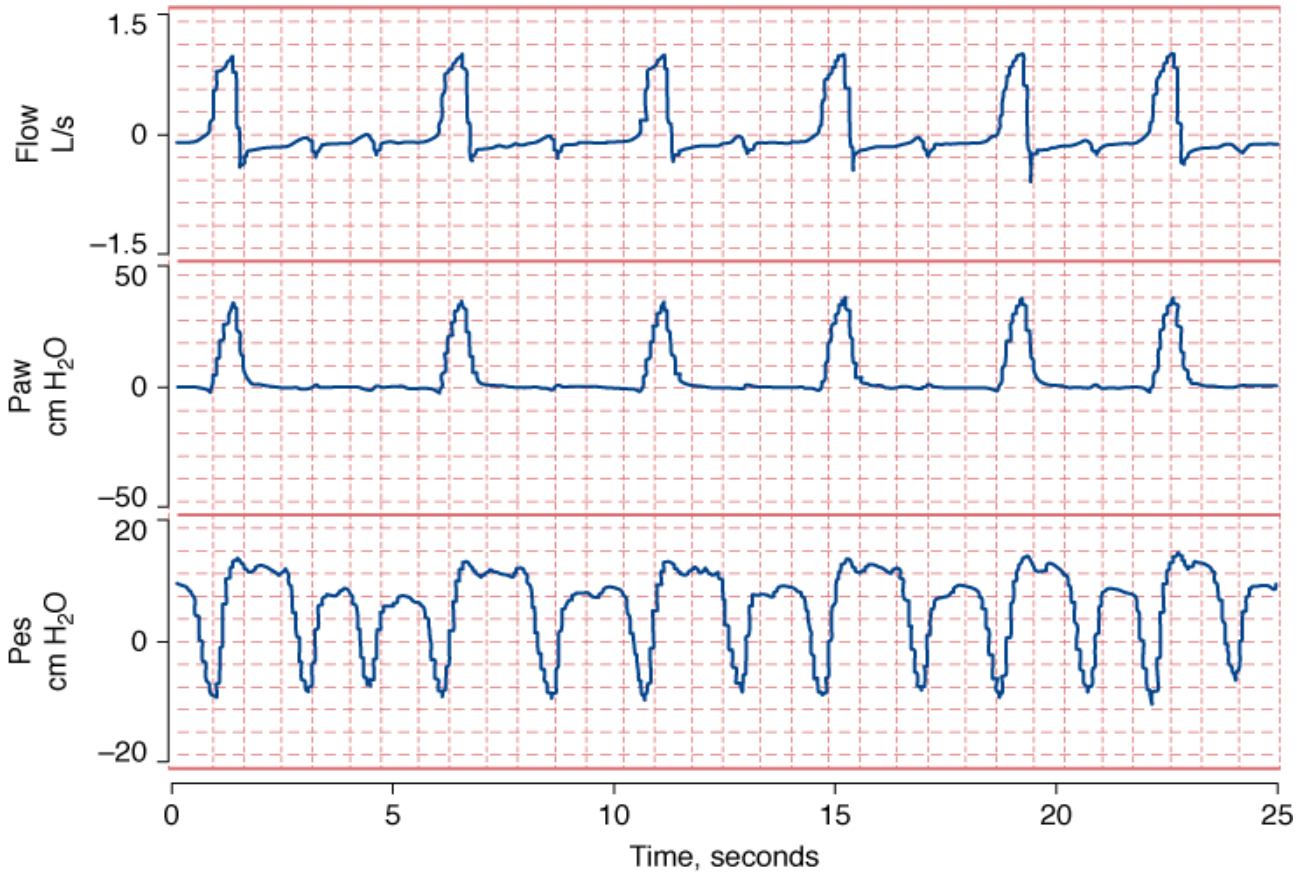


Flow trigger, sensitivity: 2 L/min

Expiratory valve malfunction

Triggering:
PEEPi (auto-PEEP)

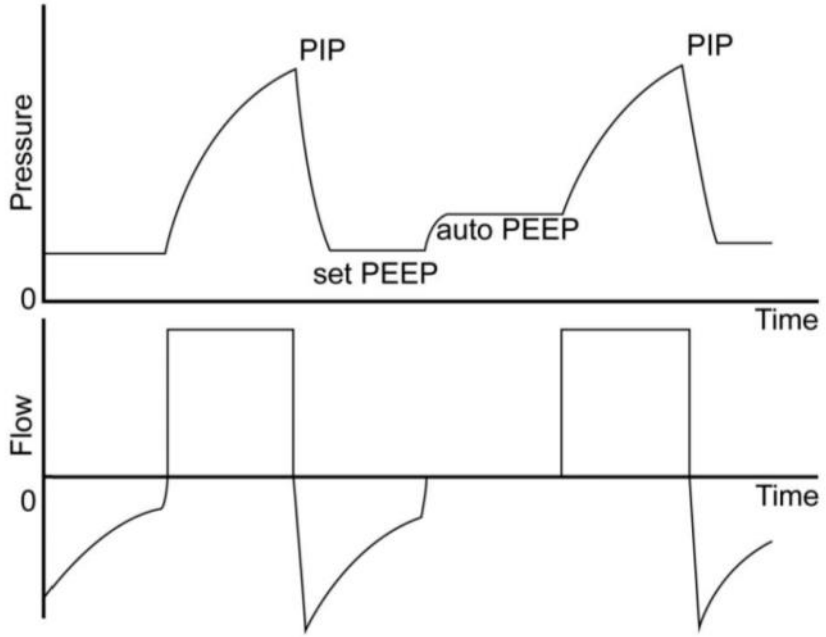
- Decrease the efficiency of respiratory muscles
- Increase WOB (triggering effort = PEEPi + Sensitivity)

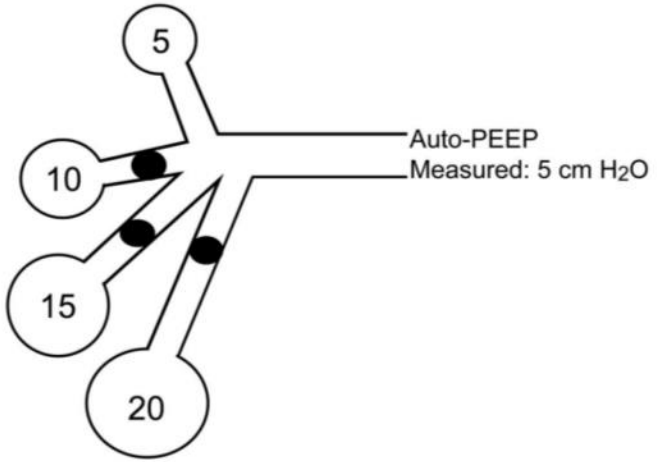


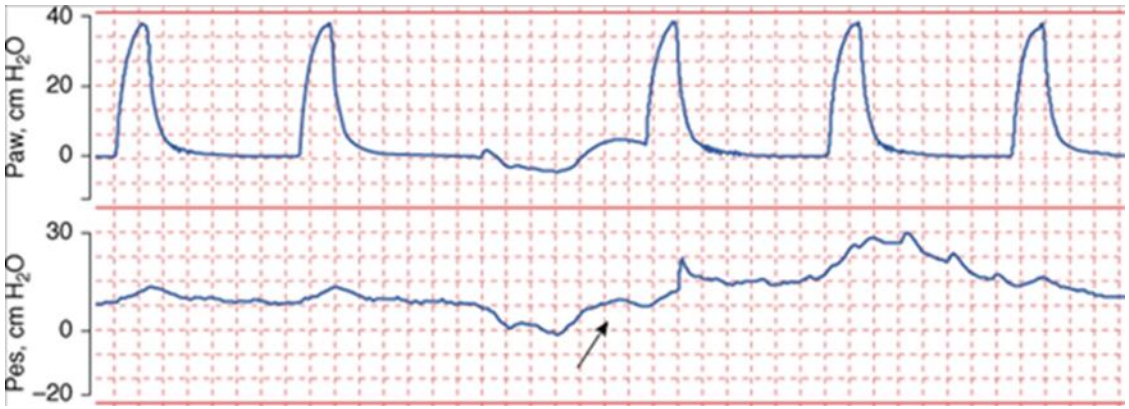
RR:
16 vs. 28/min

Source: Tobin MJ: *Principles and Practice of Mechanical Ventilation, 3rd Edition:* www.accessanesthesiology.com

Common method to measure PEEPi:
End-Expiratory Occlusion Maneuver







(could be quantified in only 30% attempts)

Respiratory Care. 2014;59:1773-1794

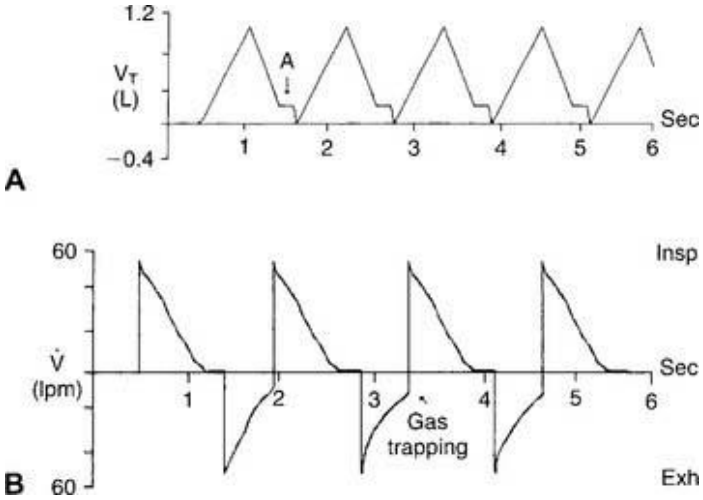
Source: Tobin MJ: *Principles and Practice of Mechanical Ventilation, 3rd Edition:* www.accessanesthesiology.com

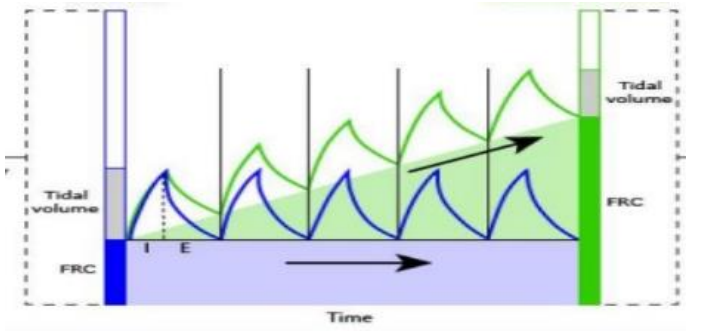
Cause of auto-PEEP

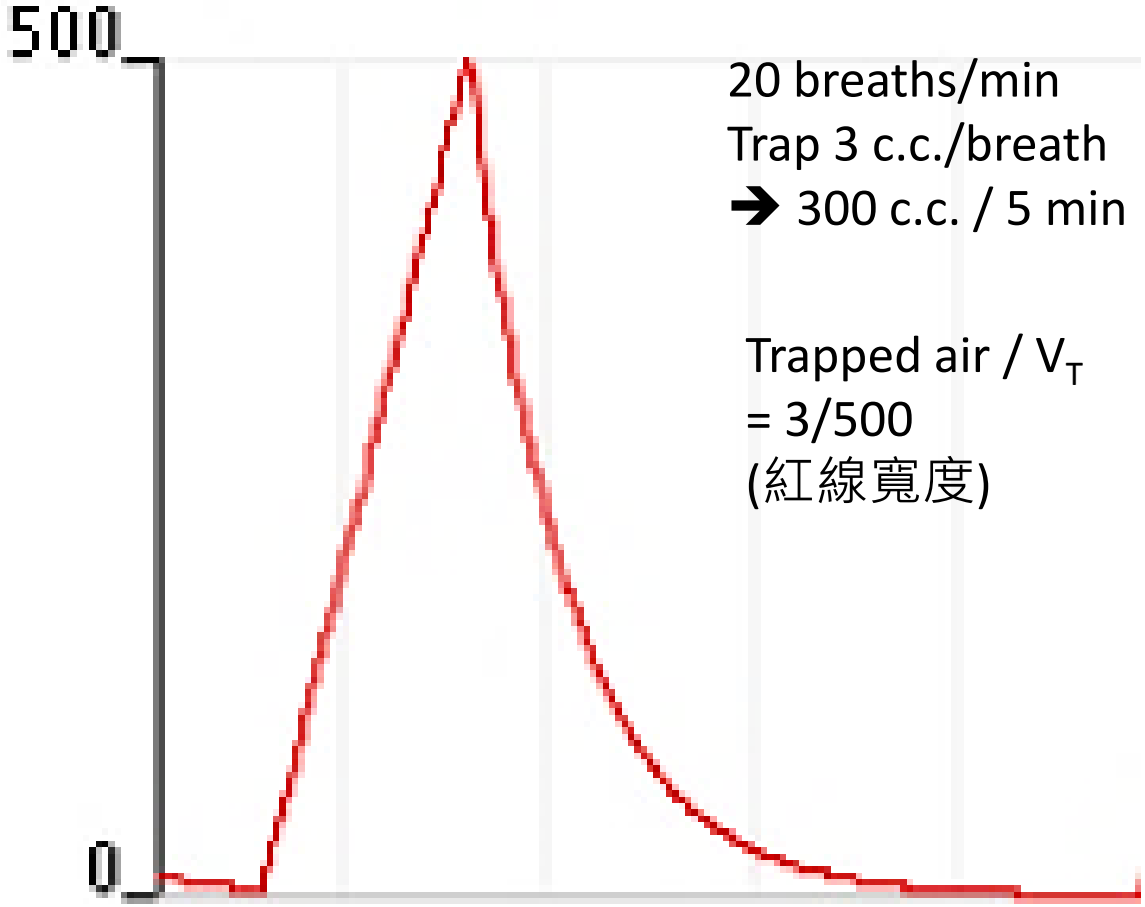
- High minute ventilation
- Flow limitation
- Expiratory time/time constant
- Resistance of the respiratory system
- Dynamic hyperinflation (reciprocal causation)
- Obesity

Respir Care. 2016;61:134-41.

It’s not feasible to identify air-trapping based on breath-by-breath waveform

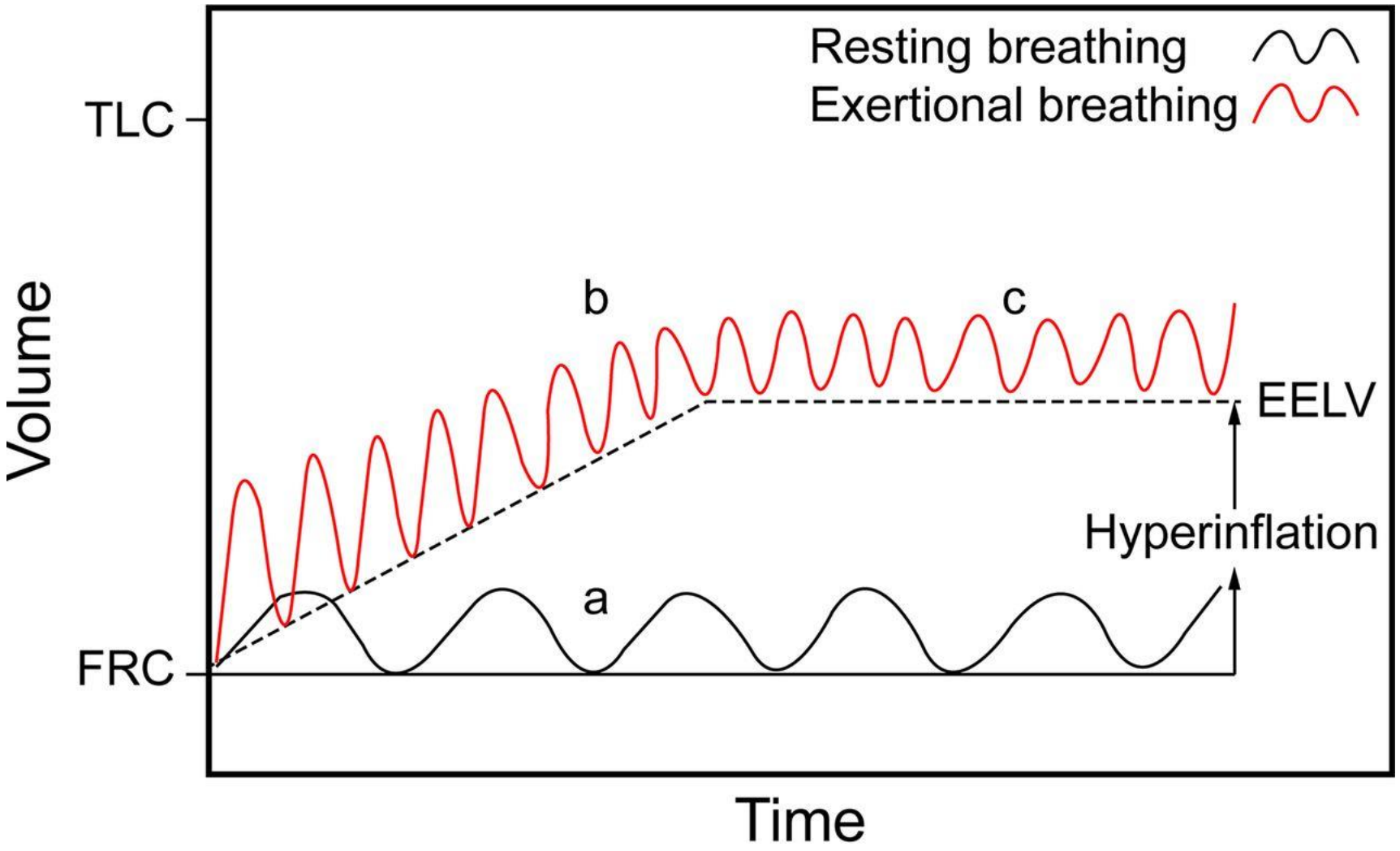




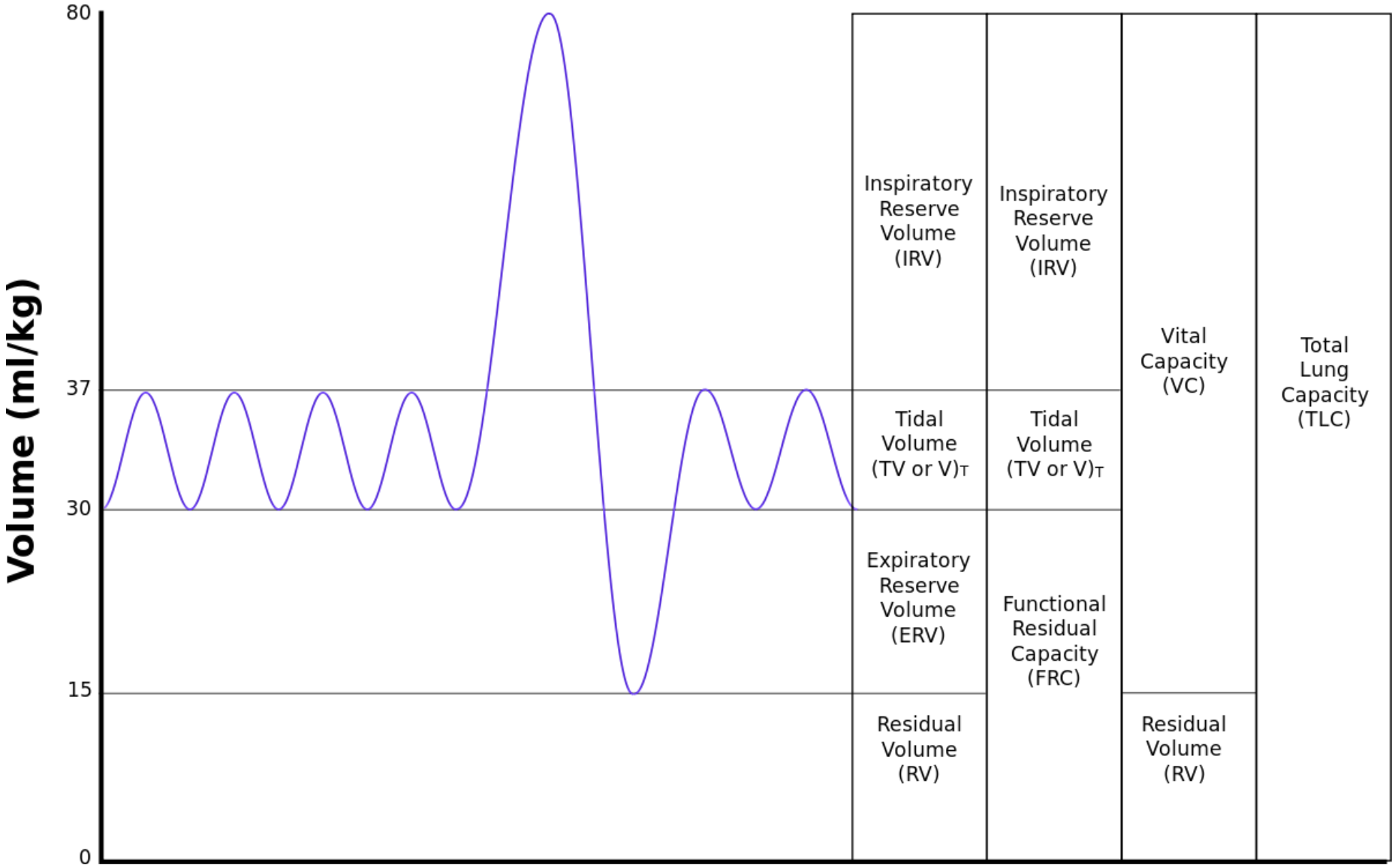


20 breaths/min
Trap 3 c.c./breath
➔ 300 c.c. / 5 min

Trapped air / V_T
= 3/500
(紅線寬度)



Respiratory Care 2017; 62:1212-1223


Volume (ml/kg)
80
37
30
15
0
Inspiratory Reserve Volume (IRV)
Tidal Volume (TV or V)T
Expiratory Reserve Volume (ERV)
Residual Volume (RV)
Inspiratory Reserve Volume (IRV)
Tidal Volume (TV or V)T
Functional Residual Capacity (FRC)
Vital Capacity (VC)
Residual Volume (RV)
Total Lung Capacity (TLC)

Solution for Auto-PEEP

- Reduce PEEPi
  - Apply PEEP to overcome auto-PEEP
  - Reduce RR, reduce T_I , increase T_E

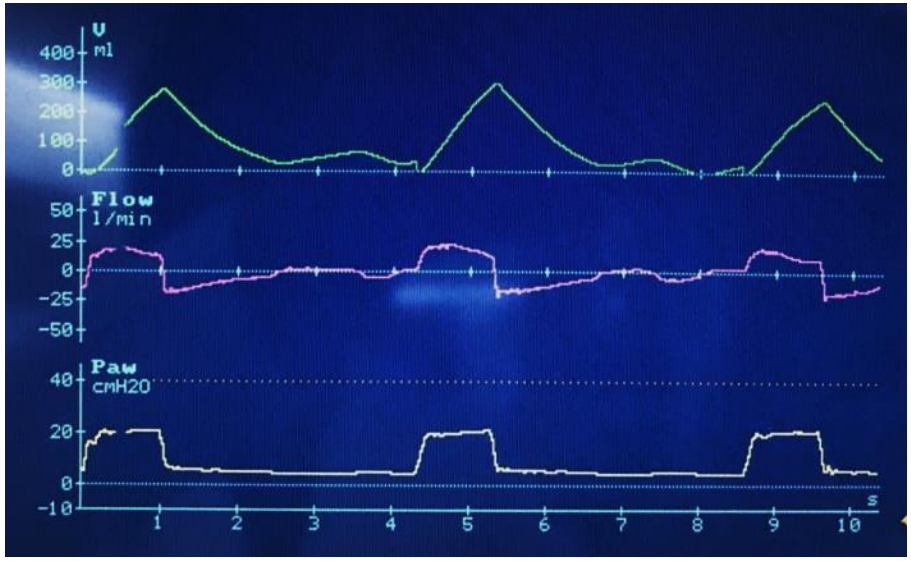
➔Correct dynamic hyperinflation ➔ Improve Compliance

TABLE 7-1 Initial Ventilator Settings Based on Pulmonary Disorder*

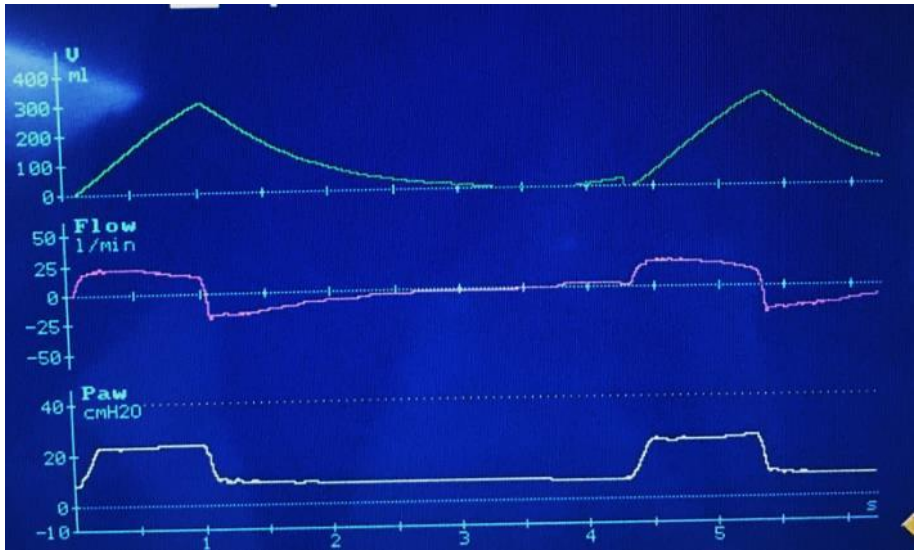
Lung Disease	Mode	V_T (mL/kg IBW)	Rate (breaths/min)	Flow (L/min)	Flow Waveform	T_I (sec)	PEEP (cm H_2O)	F_IO_2
Normal lungs	VC- or PC-CMV	6-8	10-15	60	Descending or constant	1	≤5	≤0.5
COPD†	VC- or PC-CMV	6-8	8-12	>60 (80-100)	Descending or constant	0.6-1.2	≥5 or 50% of intrinsic PEEP	<0.5

Susan P. Pilbeam, *et al*. Mechanical Ventilation: physiological and clinical applications. 5TH edition.

A case of AECOPD

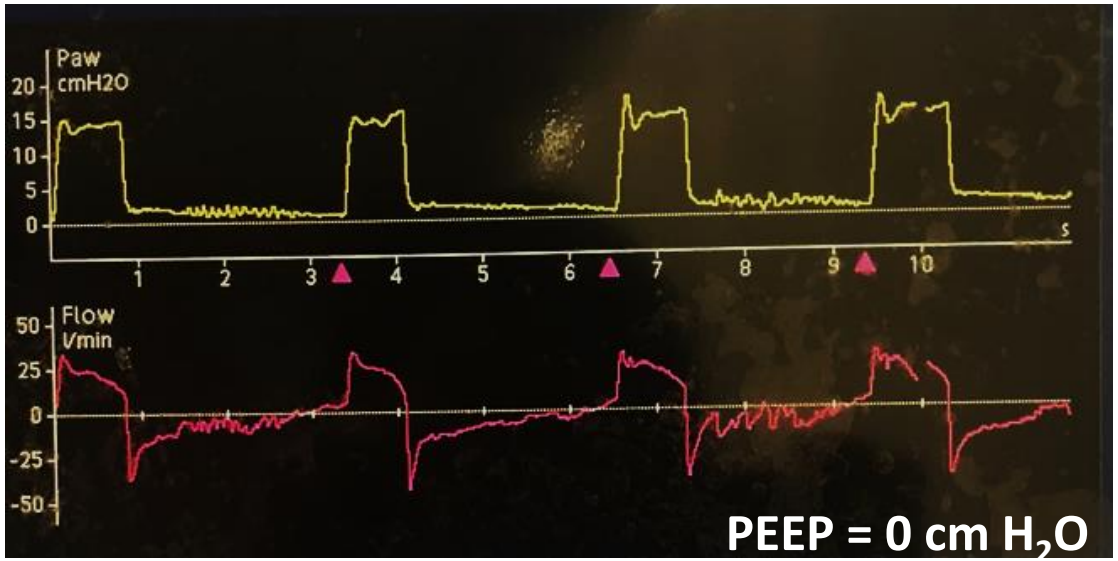


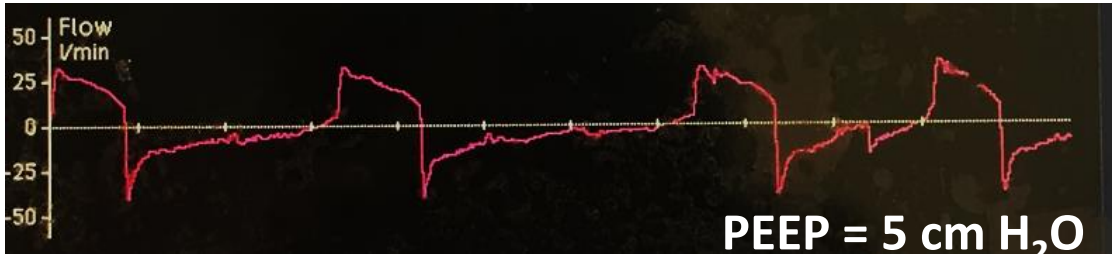
PEEP = 5 cm H_2O

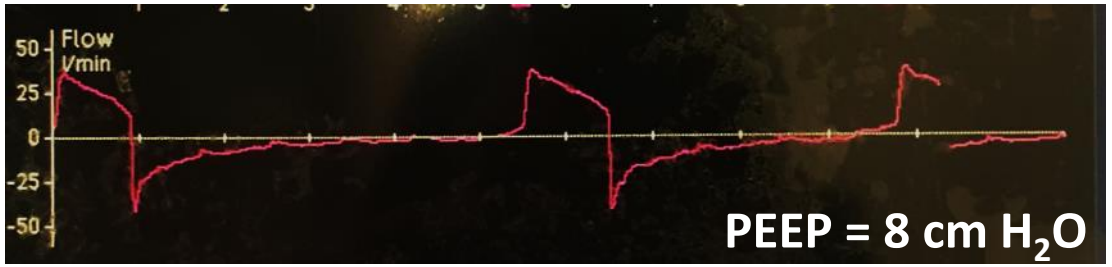


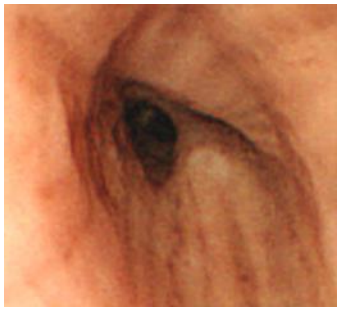
PEEP = 8 cm H_2O

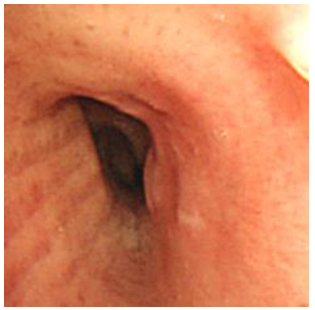
Reducing Air-Trapping, RR Decrease





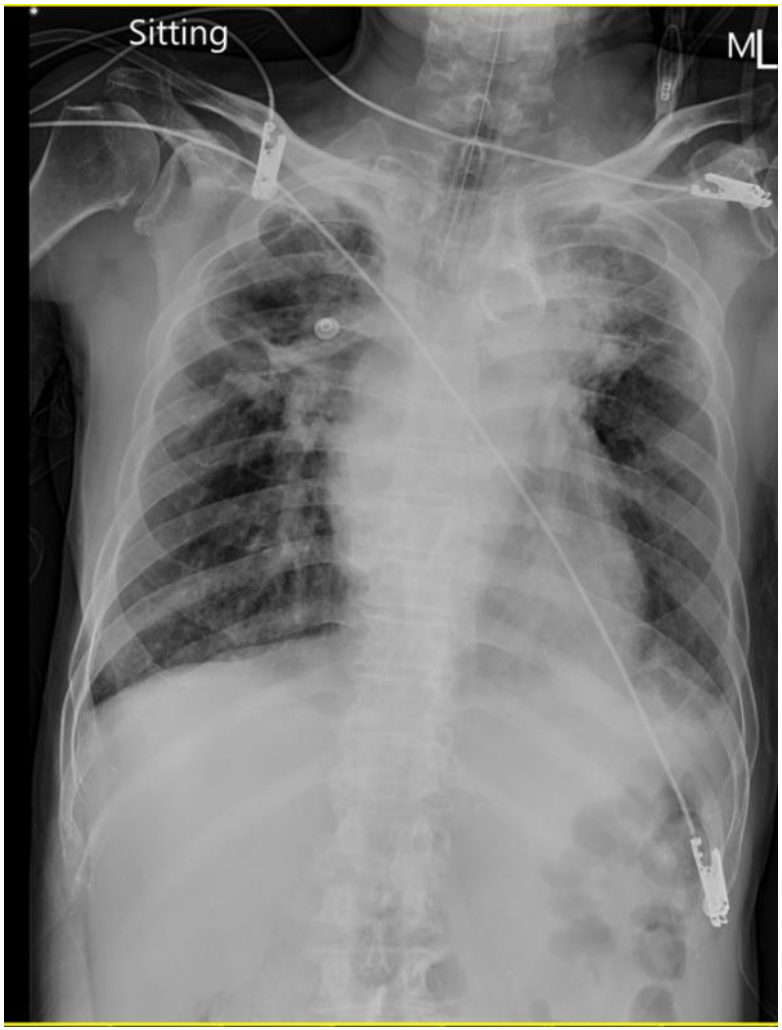






Bronchomalacia and excessive dynamic airway collapse, with expiratory flow oscillations and notching.

80 y/o male , old TB
AECOPD



Initial setting:

PCV/AC, **RR 14/min**, FiO2 40%

PEEP 5, **IP 20 cm H_2O**, T_I 1.0 second

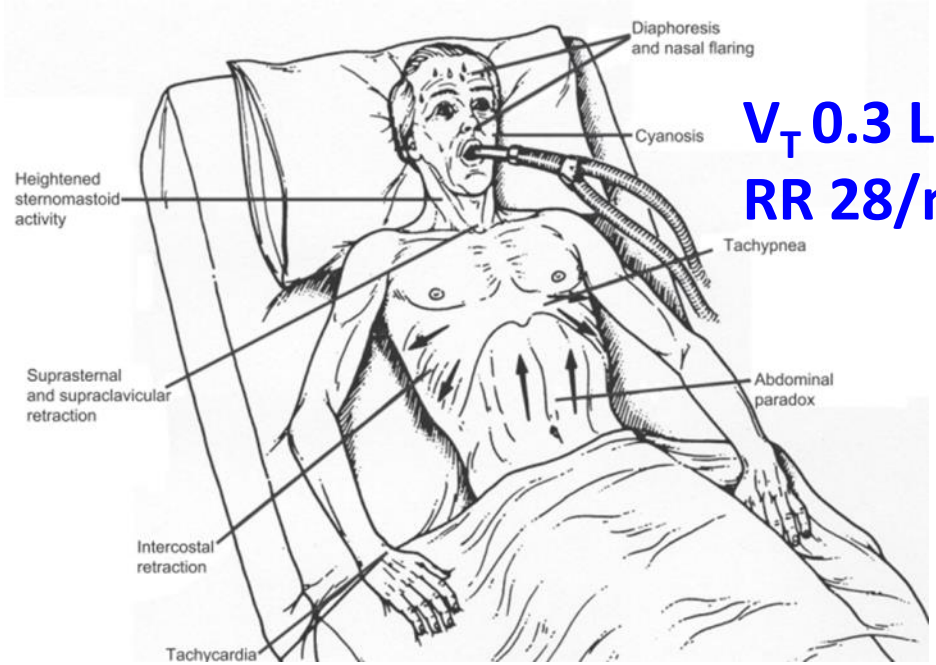
→ **V_T 0.5 L, MV 7 L/min**

pH	7.436	
pCO2	57.5	mmHg
pO2	416.3	mmHg
HCO3	37.8	mmol/L
TCO2	39.6	mmol/L
ABE	11.6	mmol/L
BEecf	13.6	mmol/L
SBC	33.5	mmol/L
O2 sat.	100.0	%

PCV/AC, **RR 20/min**, FiO2 40%

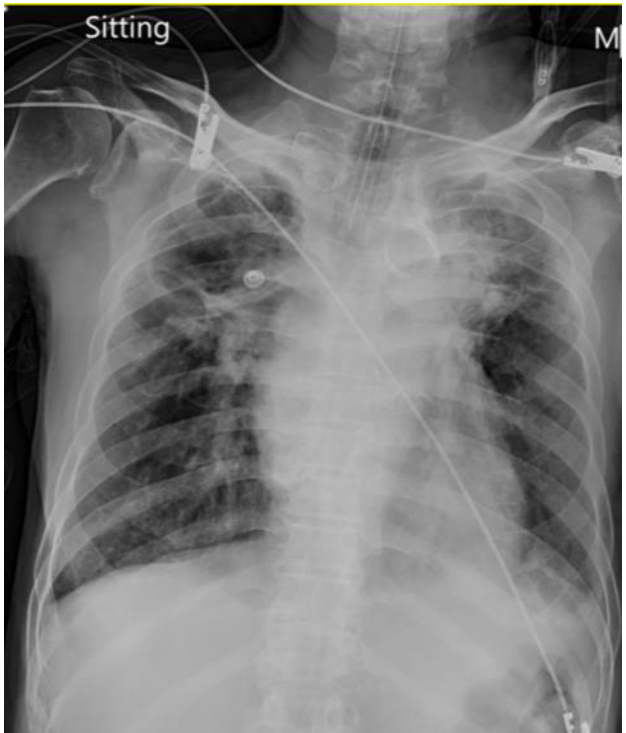
PEEP 5, **IP 24 cm H_2O**, T_I 1.0 second

→ **V_T 0.4 L, MV 8 L/min**



V_T 0.3 L,
RR 28/min

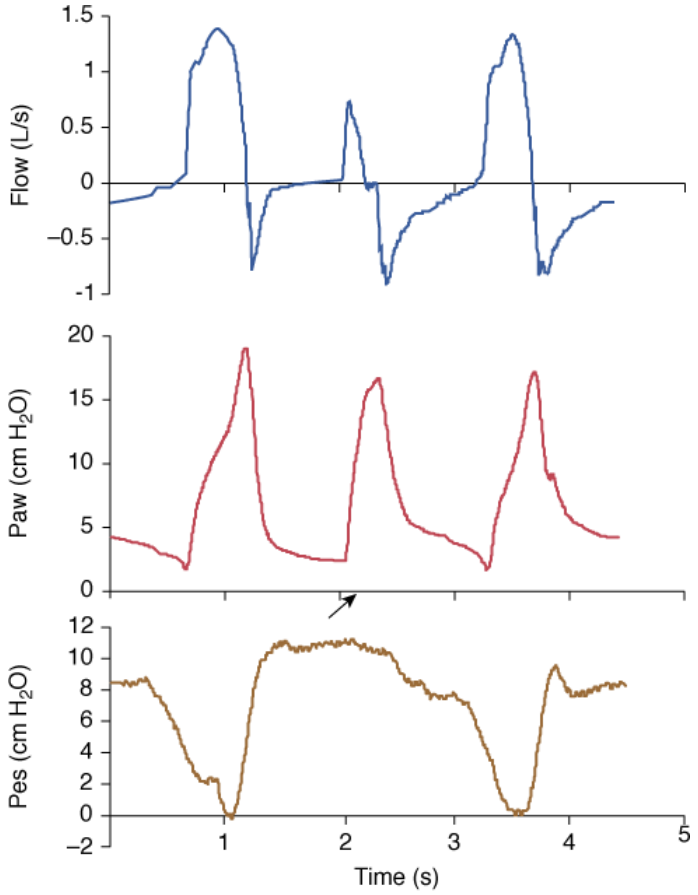
PCV/AC, **RR 10/min**,
PEEP 8, **IP 24 cm H_2O**,
T_I 0.8 second
→ VT 0.3→0.4 → 0.5 L
→ IP 20 cm H_2O,
Patient calmed down



Extra-Triggering

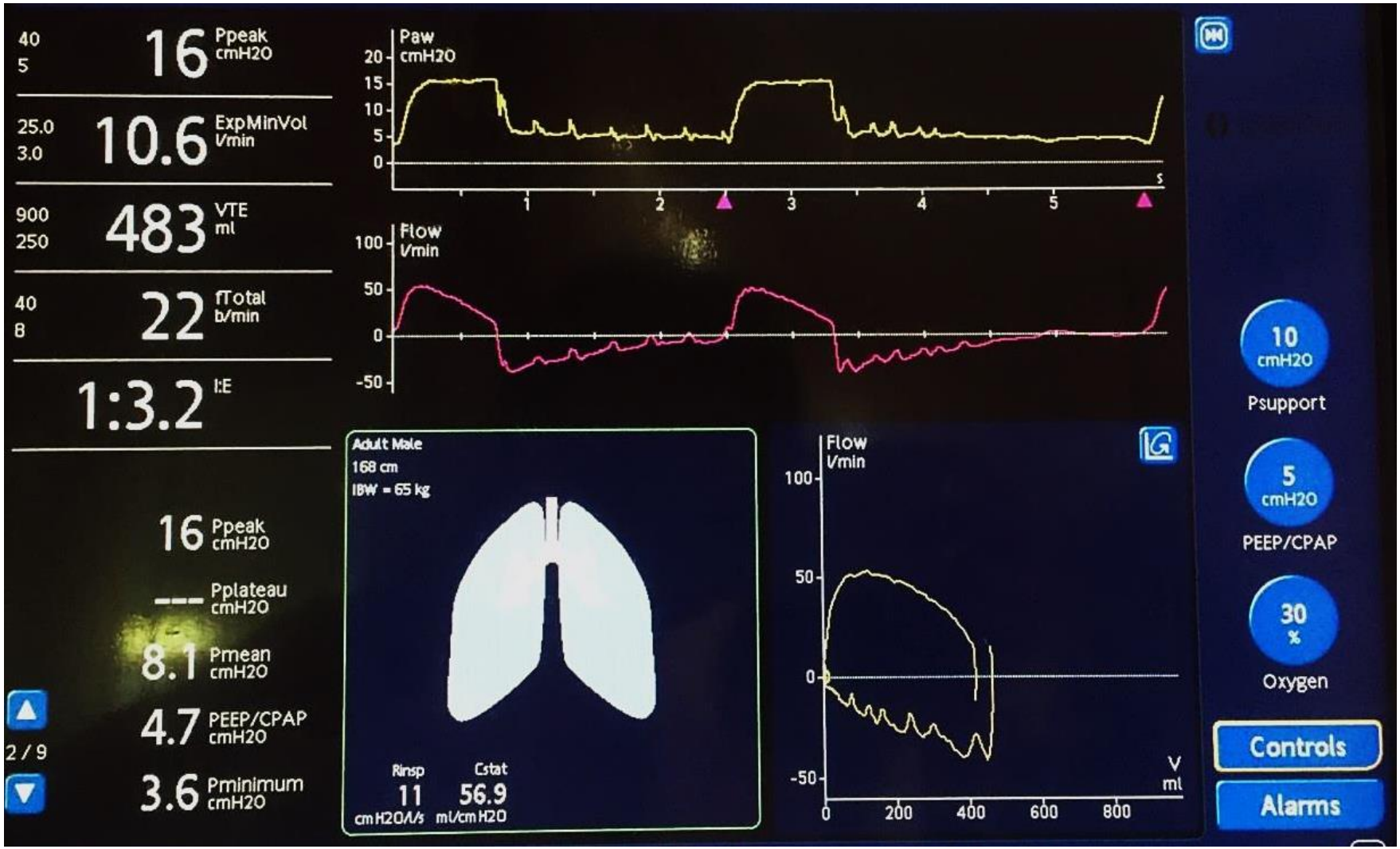
- Auto-triggering → undesired hyperventilation, PEEPi
  - Circuit leaks
  - Tube condensation
  - Cardiac oscillation
  - High frequency chest wall oscillation (VEST®)

Solution:
Reduce the triggering sensitivity

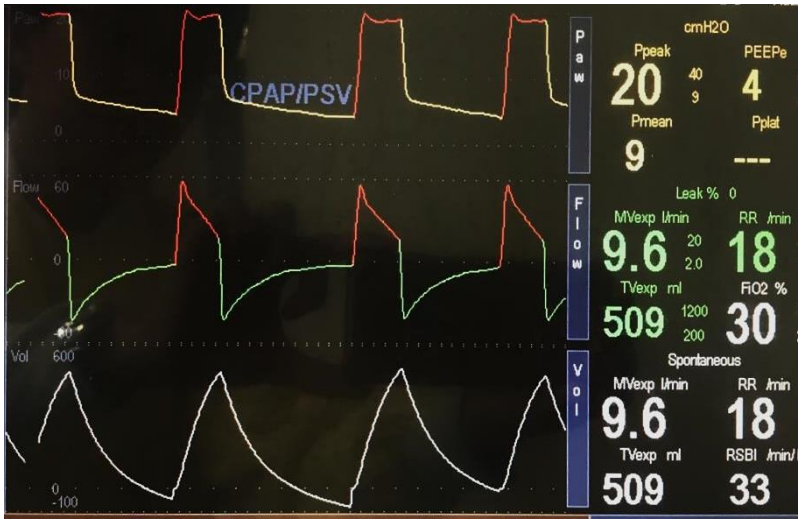


Source: Tobin MJ: *Principles and Practice of Mechanical Ventilation, 3rd Edition:* www.accessanesthesiology.com

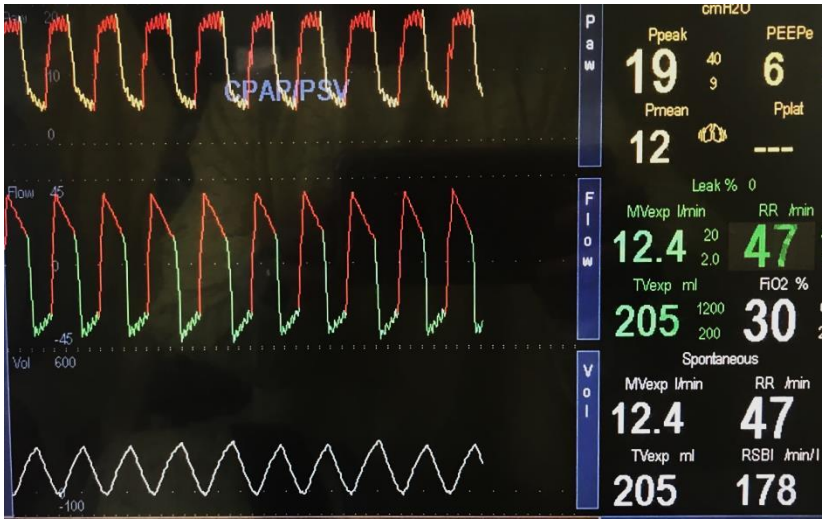
Tubing Condensation



High Frequency Chest Wall Oscillation (VEST®)



Pressure trigger, sensitivity 2 cmH_2O



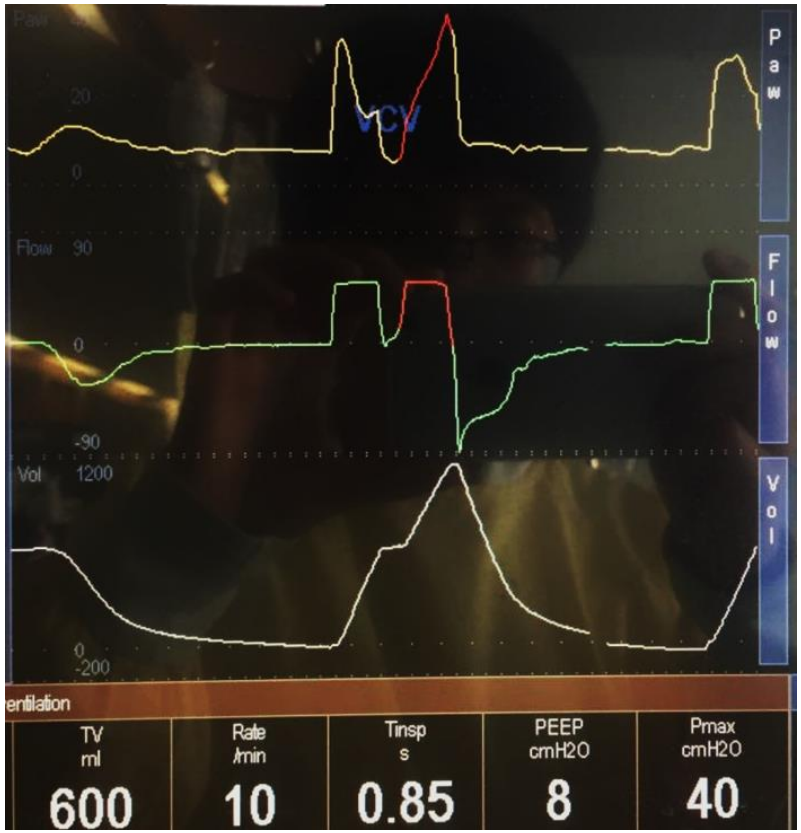
Pressure trigger, sensitivity 2 cmH_2O

VEST Off → On

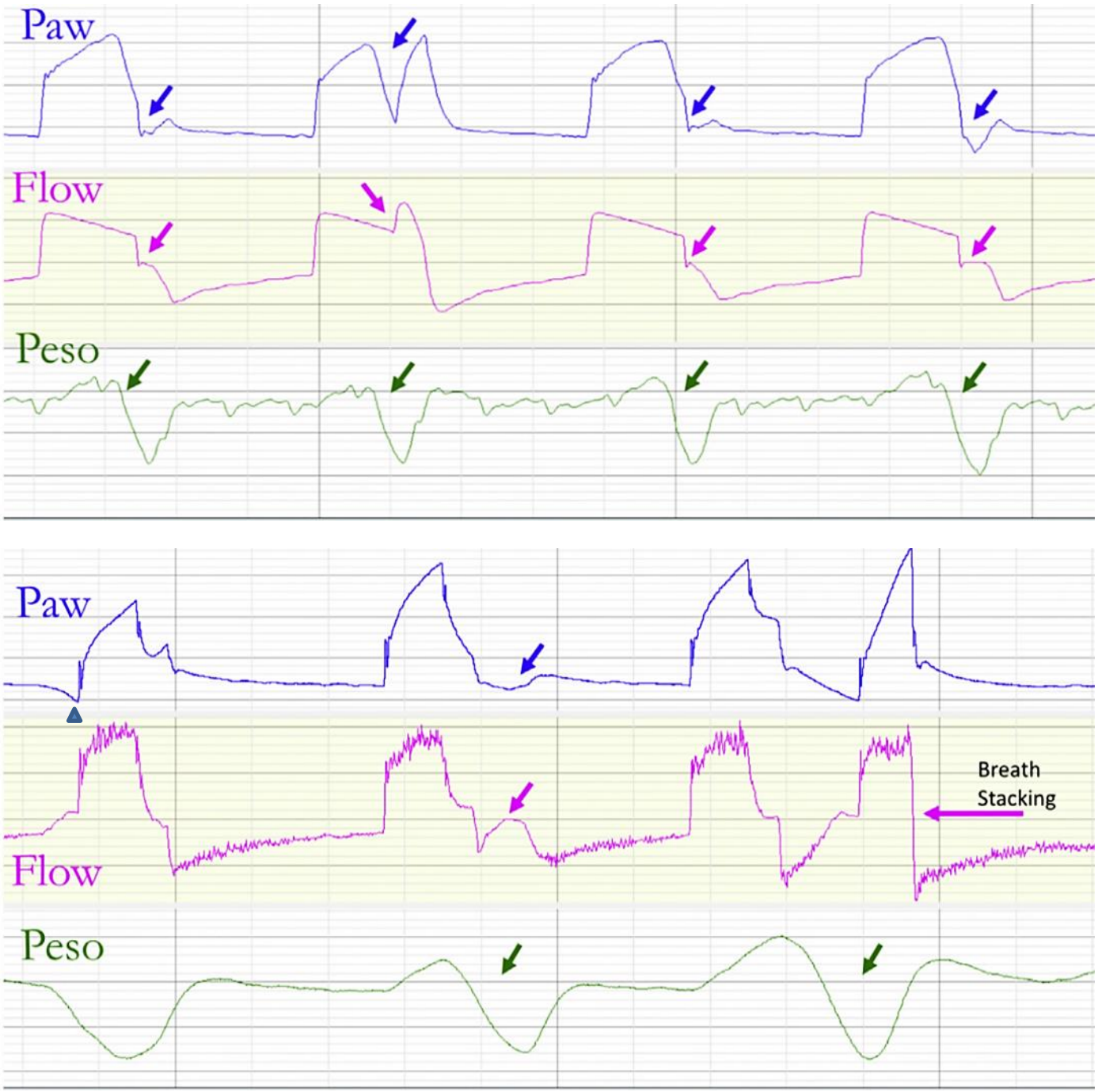
Flow trigger, sensitivity 2 L/min

Reverse Triggering

- "**Entrainment**"
- The phenomenon of a machine-triggered mechanical breath eliciting a spontaneous effort.
- Cause: vagal pathway, mechanical stretch receptors, or spinal respiratory pattern generator…
- Often occurs in **heavily sedated patients with high control breath rate setting**
- 1:1, or less commonly, in 1:2 or 1:3 relationships with the control breath.



Chest 2013;143:927-938



Reverse Triggering

Ineffective effort

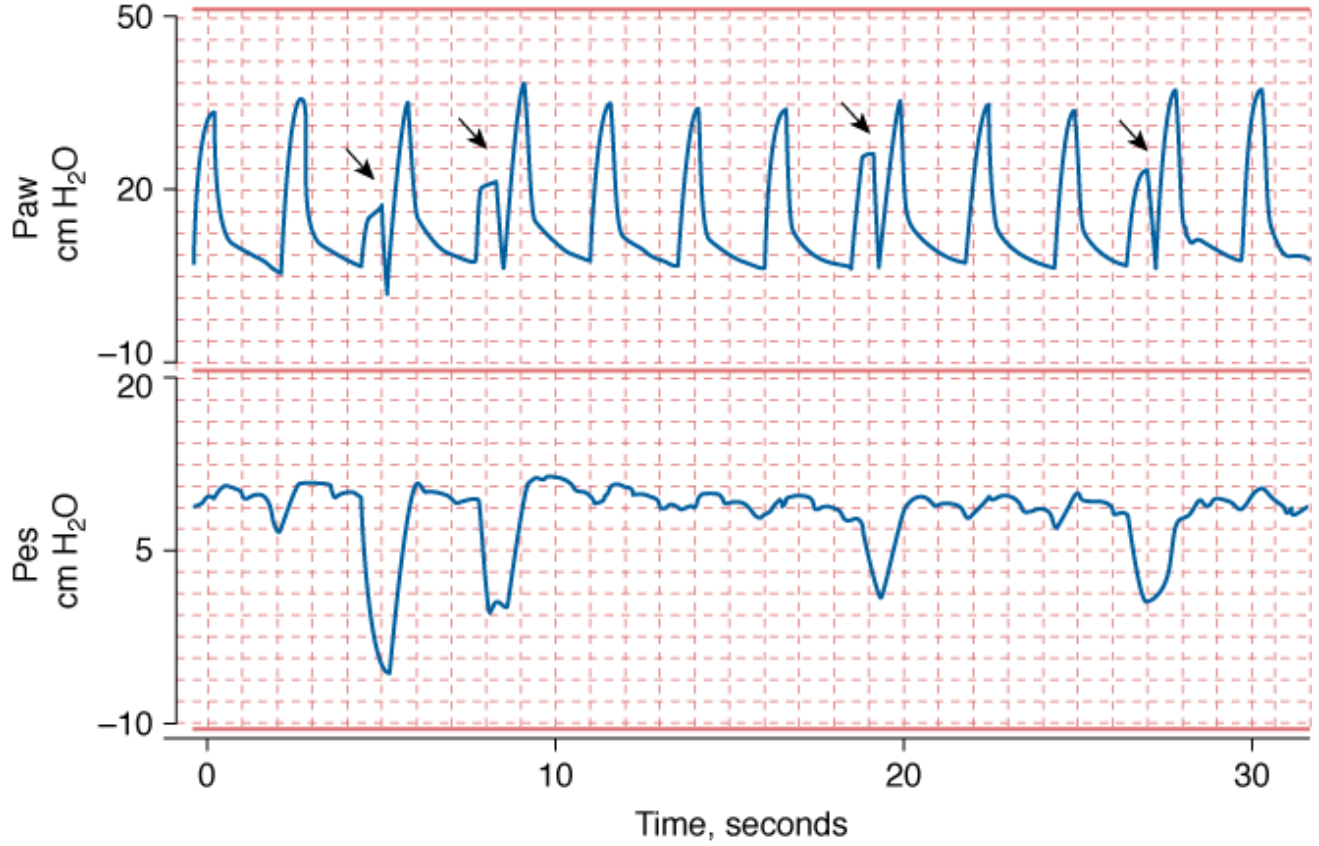
Double cycling

Breath-stacking

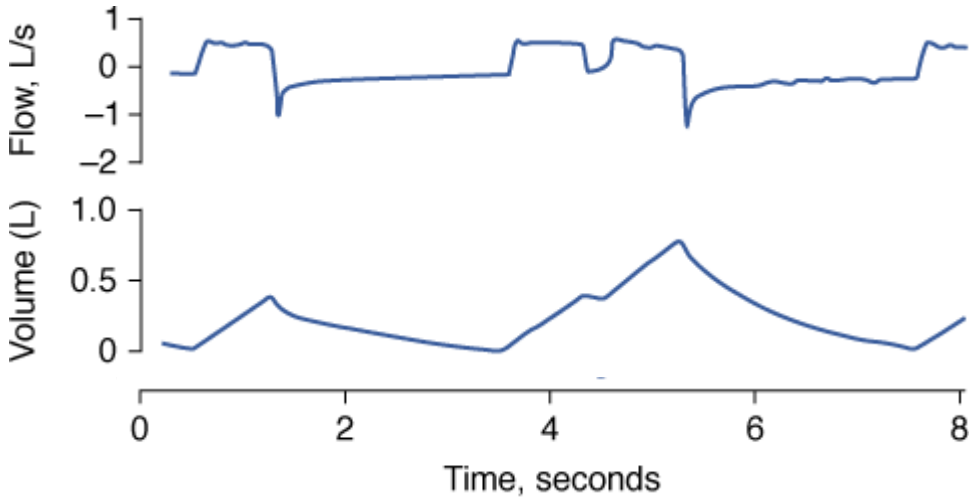
Crit Care Clin 2018;34:325–341

Double Triggering

- Premature cycling of patient-triggered breath
  - Neural T_I > Machine T_I
  - Low tidal volume strategy



Double Triggering



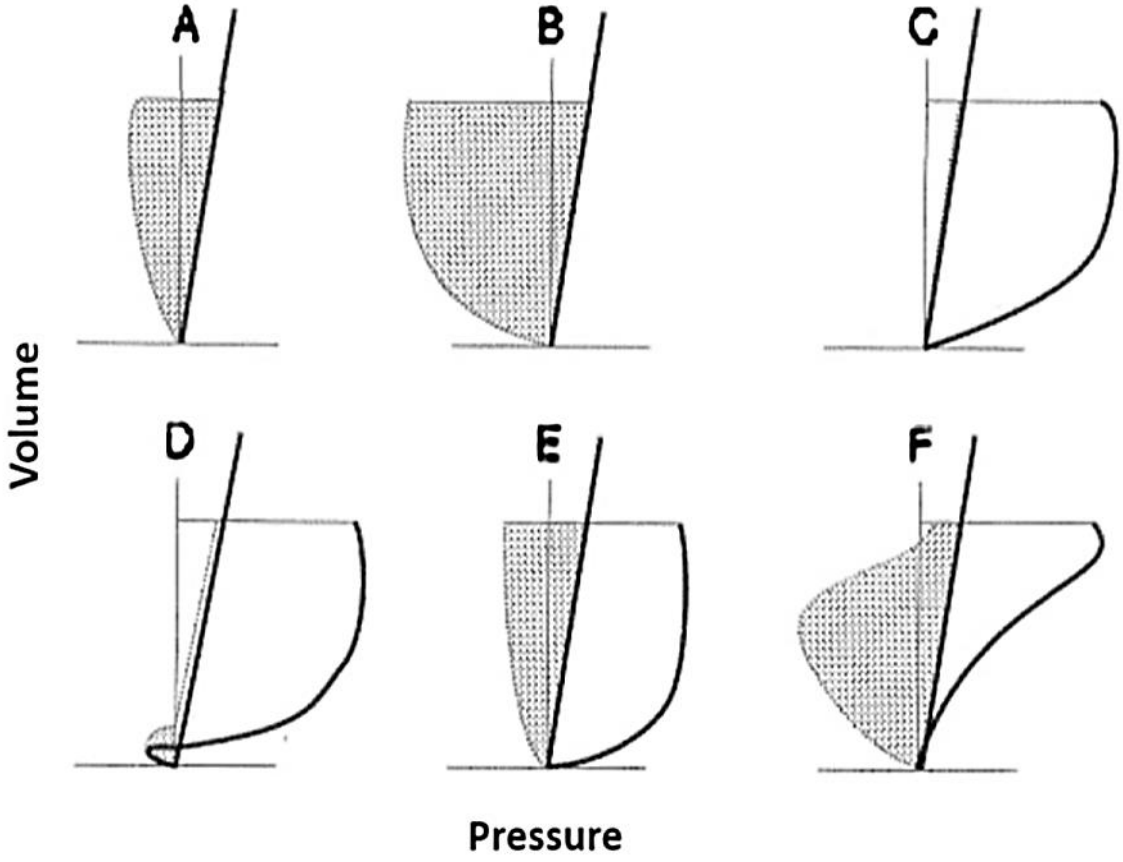
volume stacking

Solution of double triggering:

Lengthen cycle criteria (volume, time, flow)

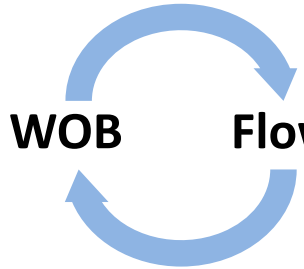
Flow (Pressure) Dyssynchrony

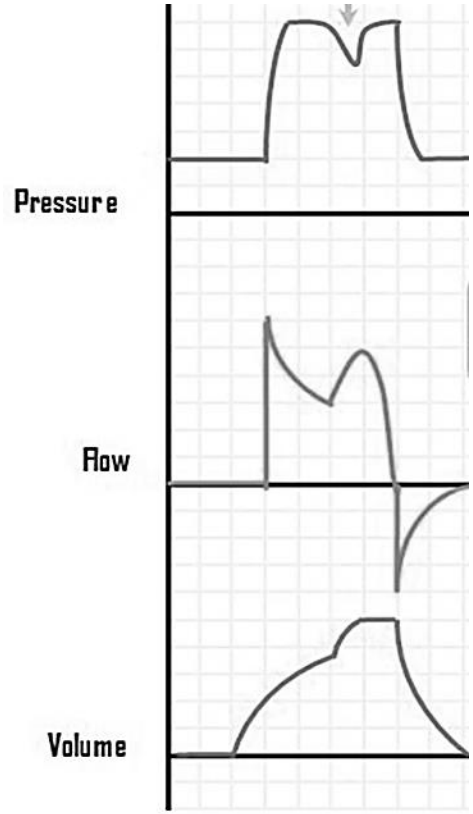
A Normal subject
B Respiratory failure without ventilator
C Patient B is receiving ventilator to support all WOB
D Patient is performing only enough work to trigger an assisted breath
E The assistance provided by the ventilator is such that the patient work pattern resembles normal
F The ventilator assistance is placing unphysiologic workloads on the patient.



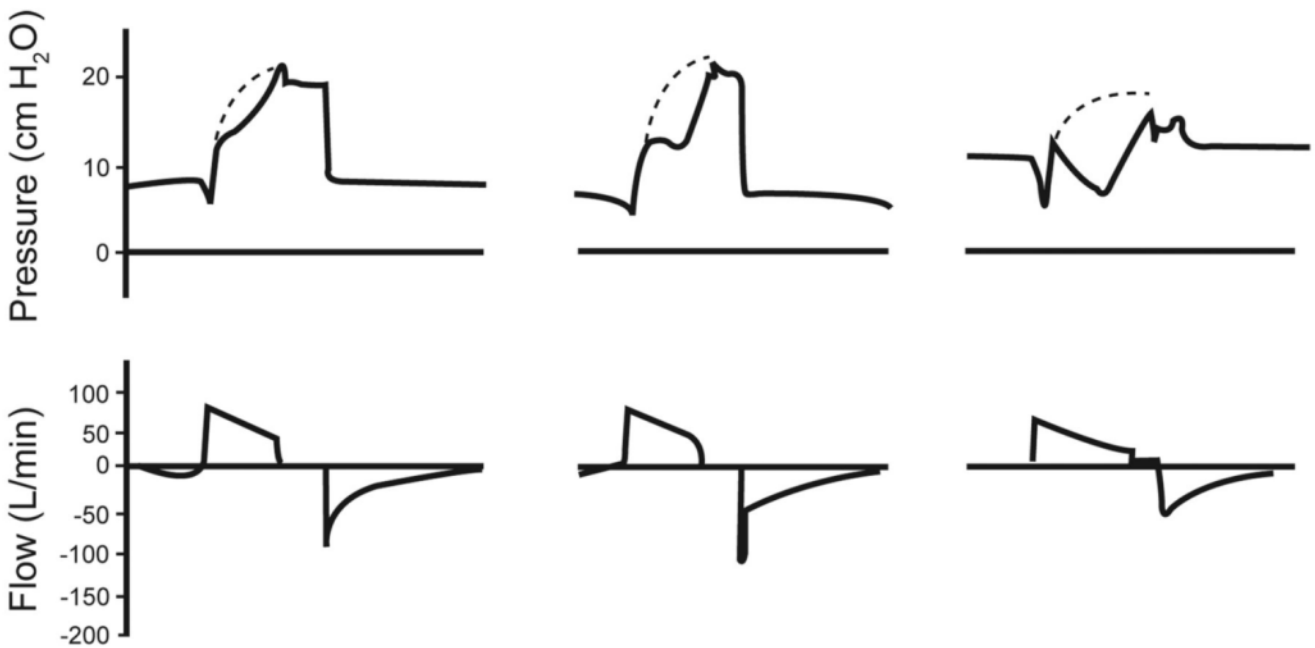
AJRCCM 2013;188:1058-1068

Inadequate Flow





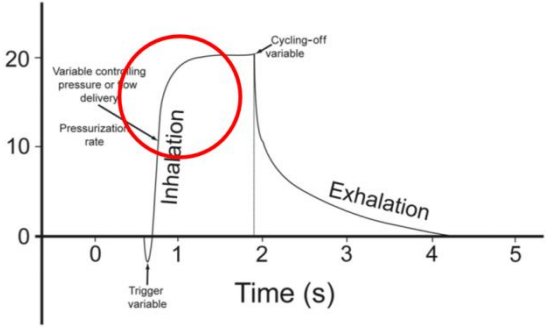
Pressure support ventilation



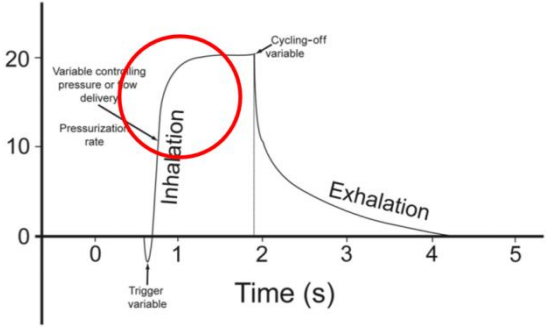
Volume assist-control with decelerating flow

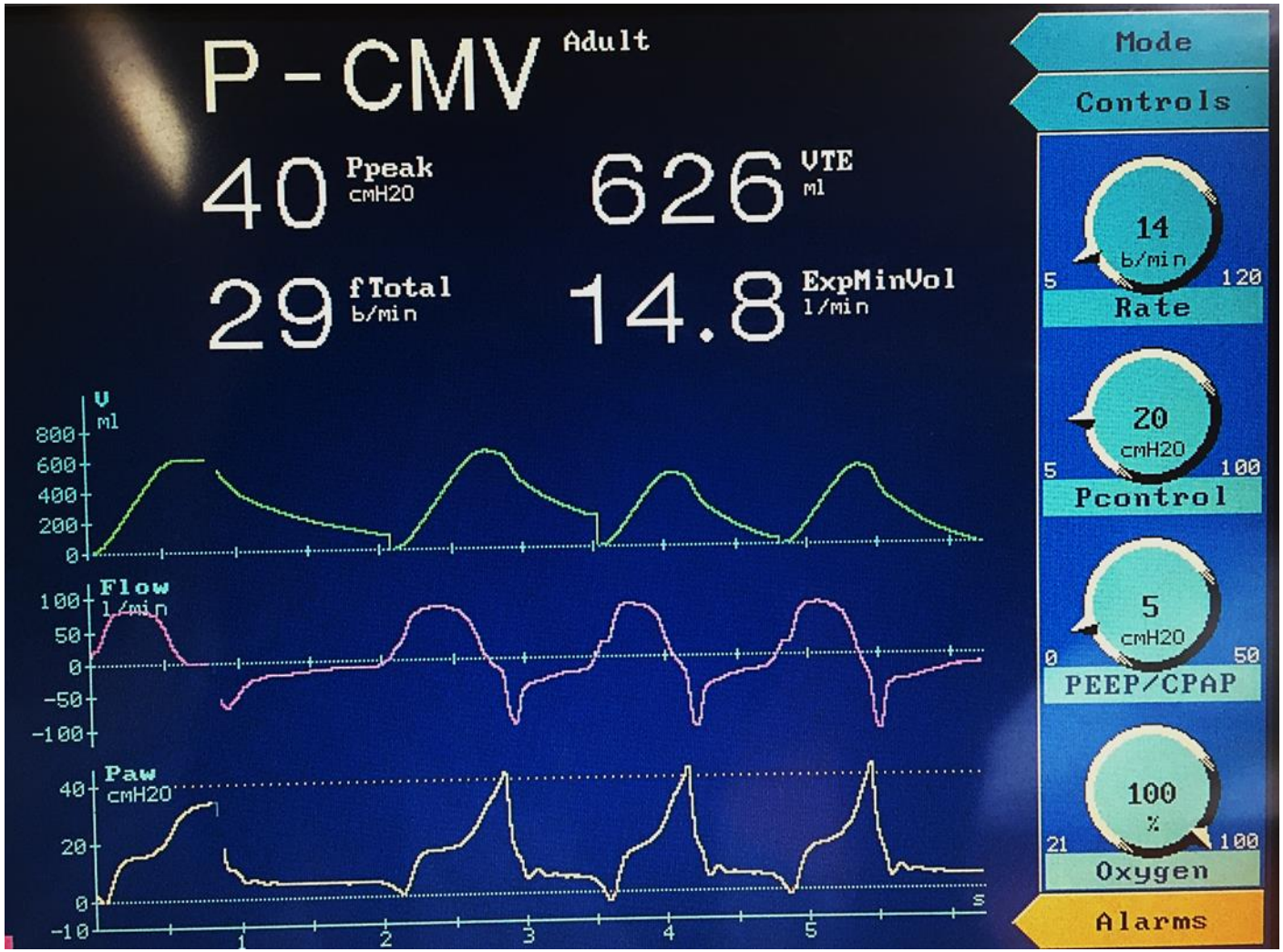
J Crit Care 2007;22:252-257.

Inadequate Flow



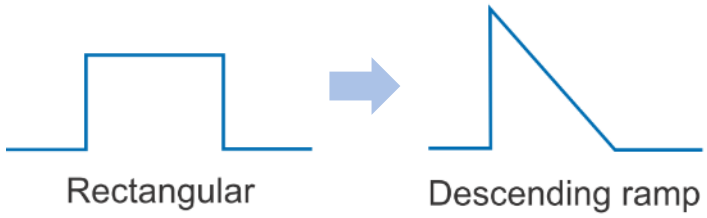
Inadequate Flow

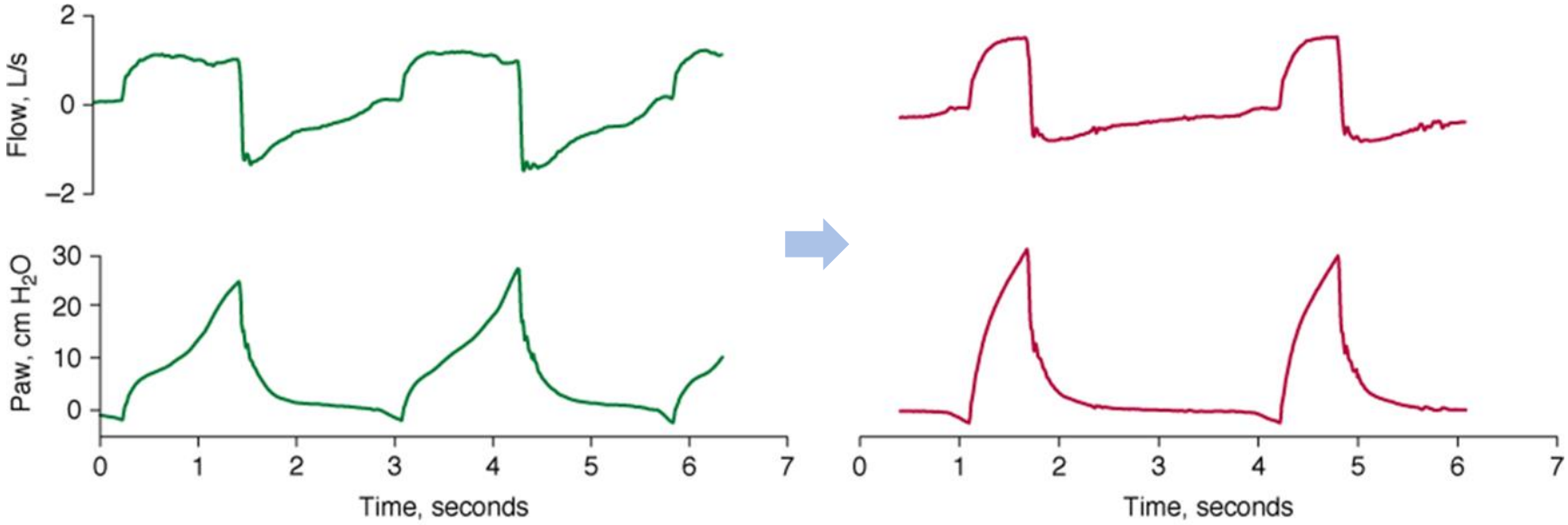




Possible Solutions for Inadequate Flow-1

- Change flow pattern
- Increase flow (pressure)

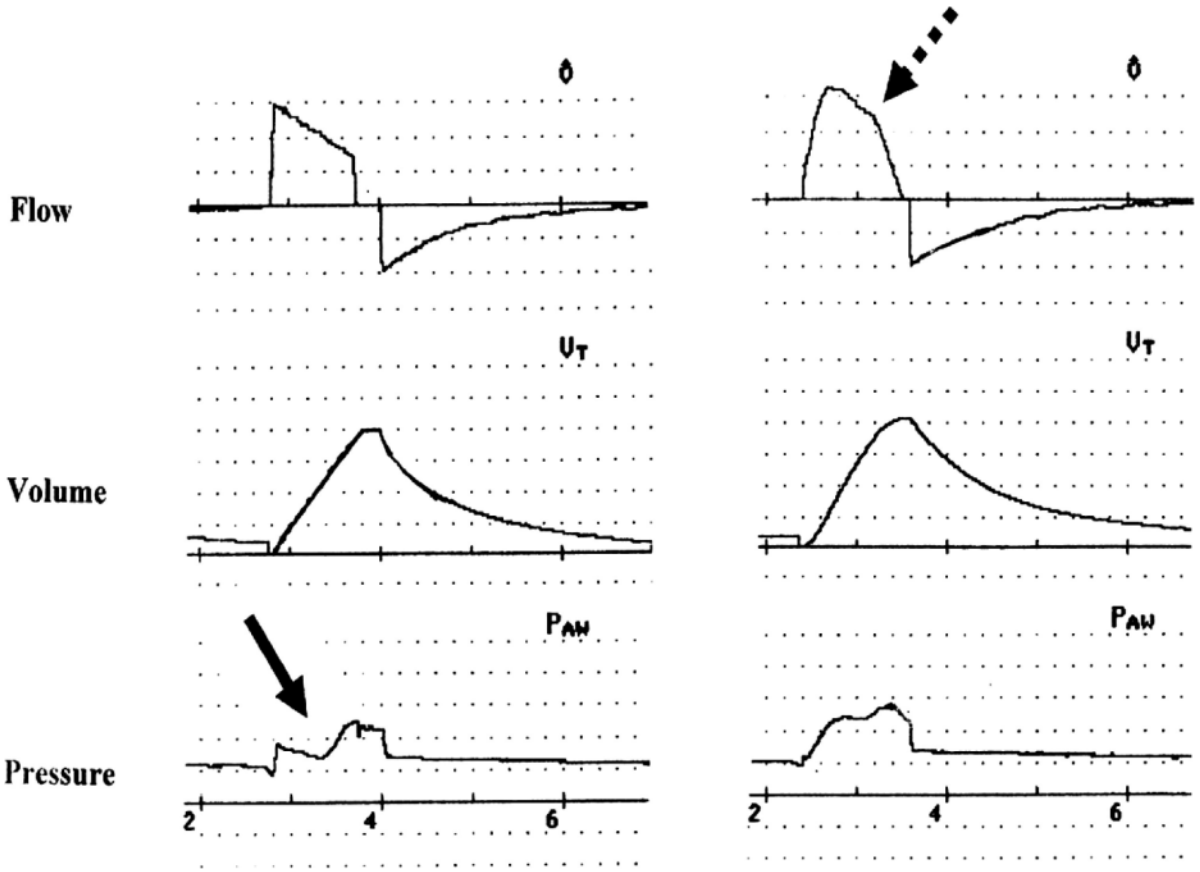




AJRCCM 2013;188:1058-1068

Possible Solutions for Inadequate Flow-2

- Use variable flow (pressure targeting)

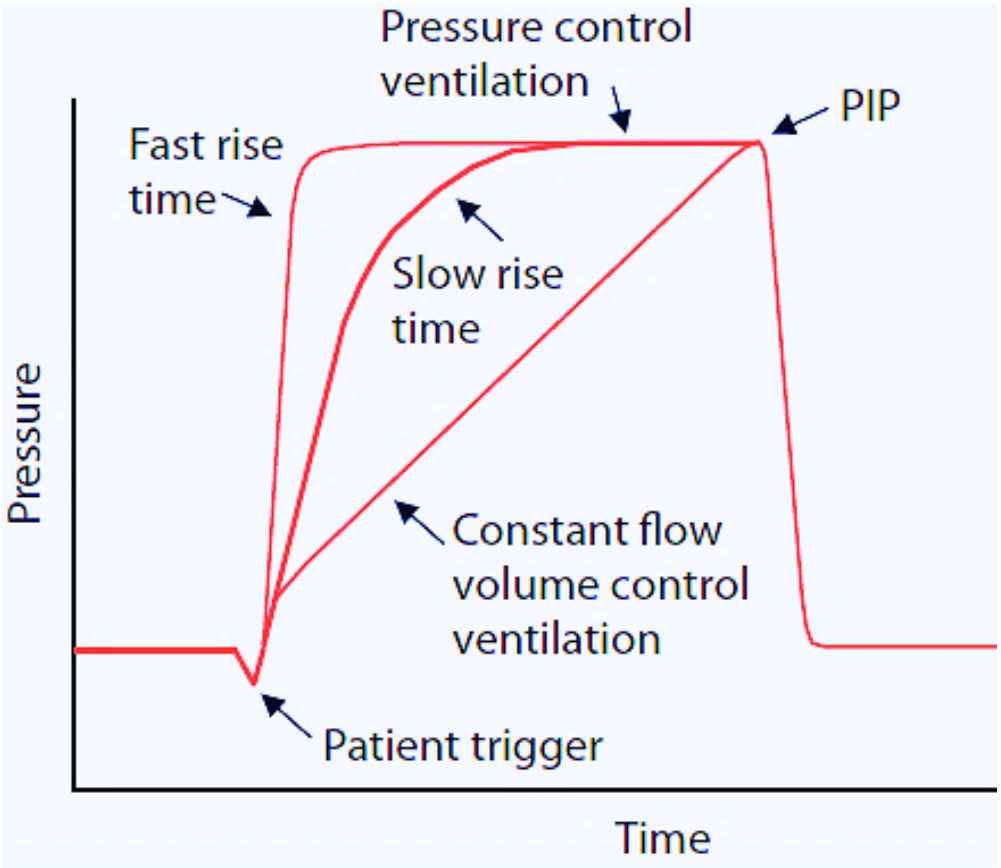


Volume control, descending flow pattern → Pressure control

Huang, et al. *J Crit Care* 2007;22:252–257.

Possible Solutions for Inadequate Flow-3

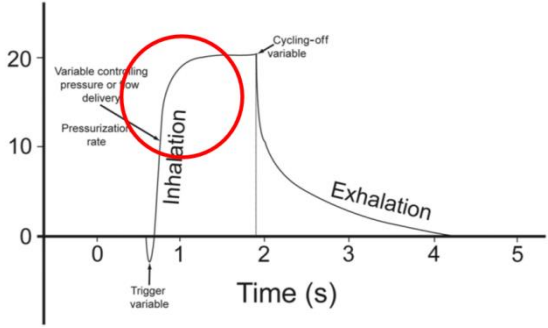
- Adjust pressure rise time
- Address excessive drive
- Let it be ?



Source: Dean R. Hess, Robert M. Kacmarek: Essentials of Mechanical Ventilation, 3rd Edition

AJRCCM 2013;188:1058-1068

Excessive Flow or Pressure



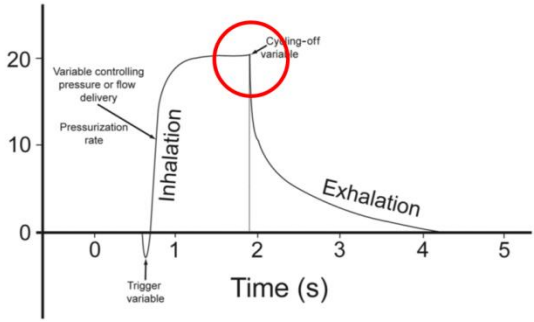
- High V_T: Ventilator-induced lung injury
- Disuse atrophy of muscles
- Periodic breathing, interference sleep
- Abruptly terminate inspiratory effort / activate expiratory muscles

Solution:

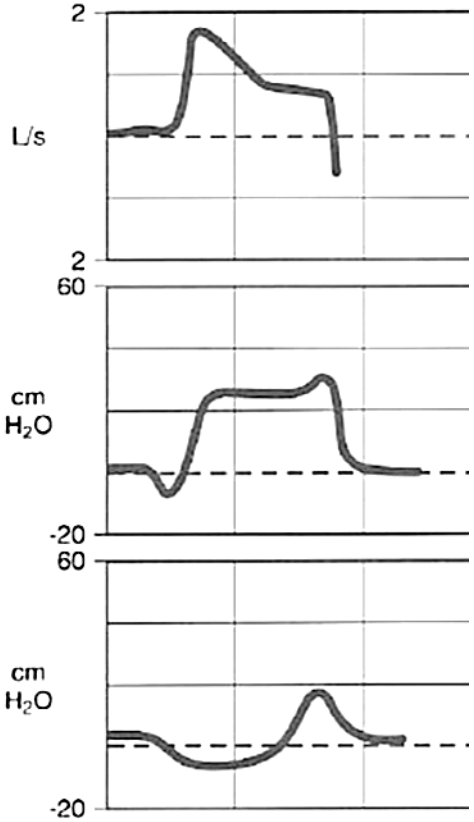
- Reduce set flow or pressure target
- Reduce pressure rise time

AJRCCM 2002;166:1423-1429
AJRCCM 1999;159:710-719

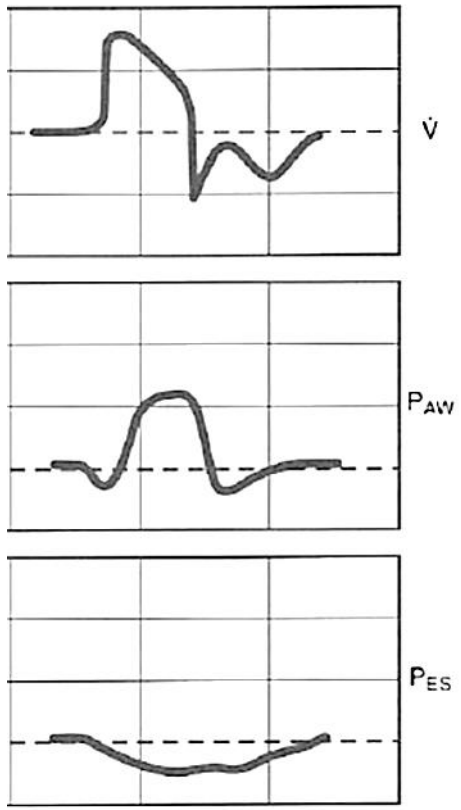
Cycling Dyssynchrony



Neural T_I < Machine T_I



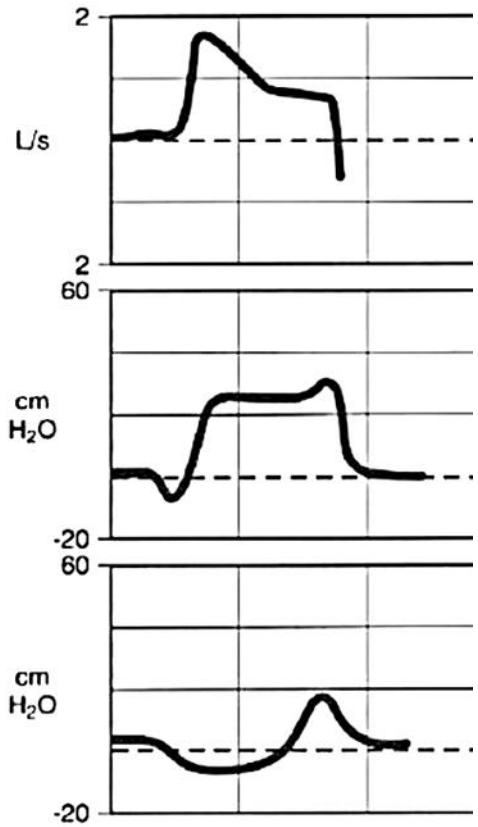
Neural T_I > Machine T_I



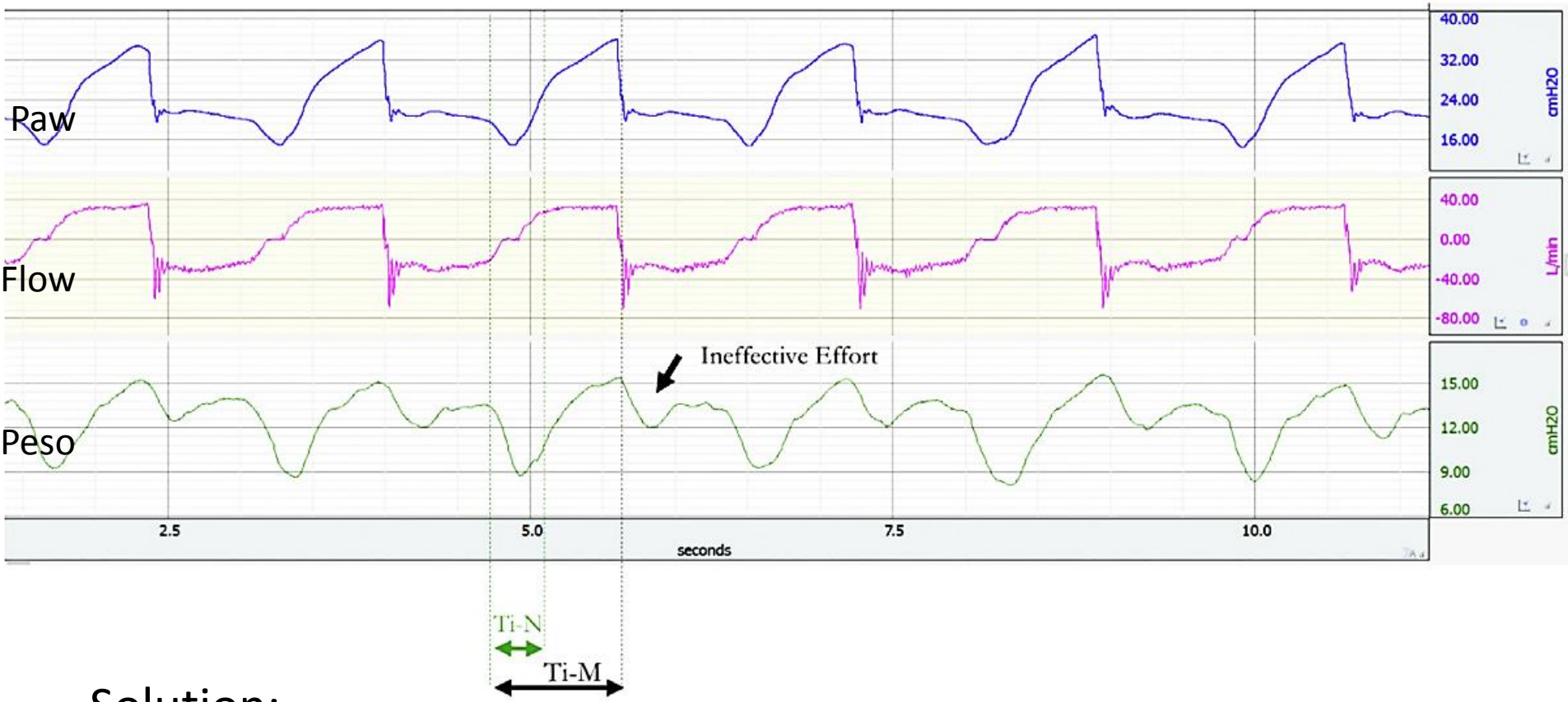
MacIntyre N, Branson R, editors. Mechanical ventilation. :Philadelphia WB Saunders; 2001.

Neural T_I < Machine T_I

- Patient's reduced ventilatory drive
- **Delayed cycling**
  - Discomfort, expiratory effort
  - Higher V_T
  - PEEPi and dynamic hyperinflation
  - Overassistance



Delayed Cycling

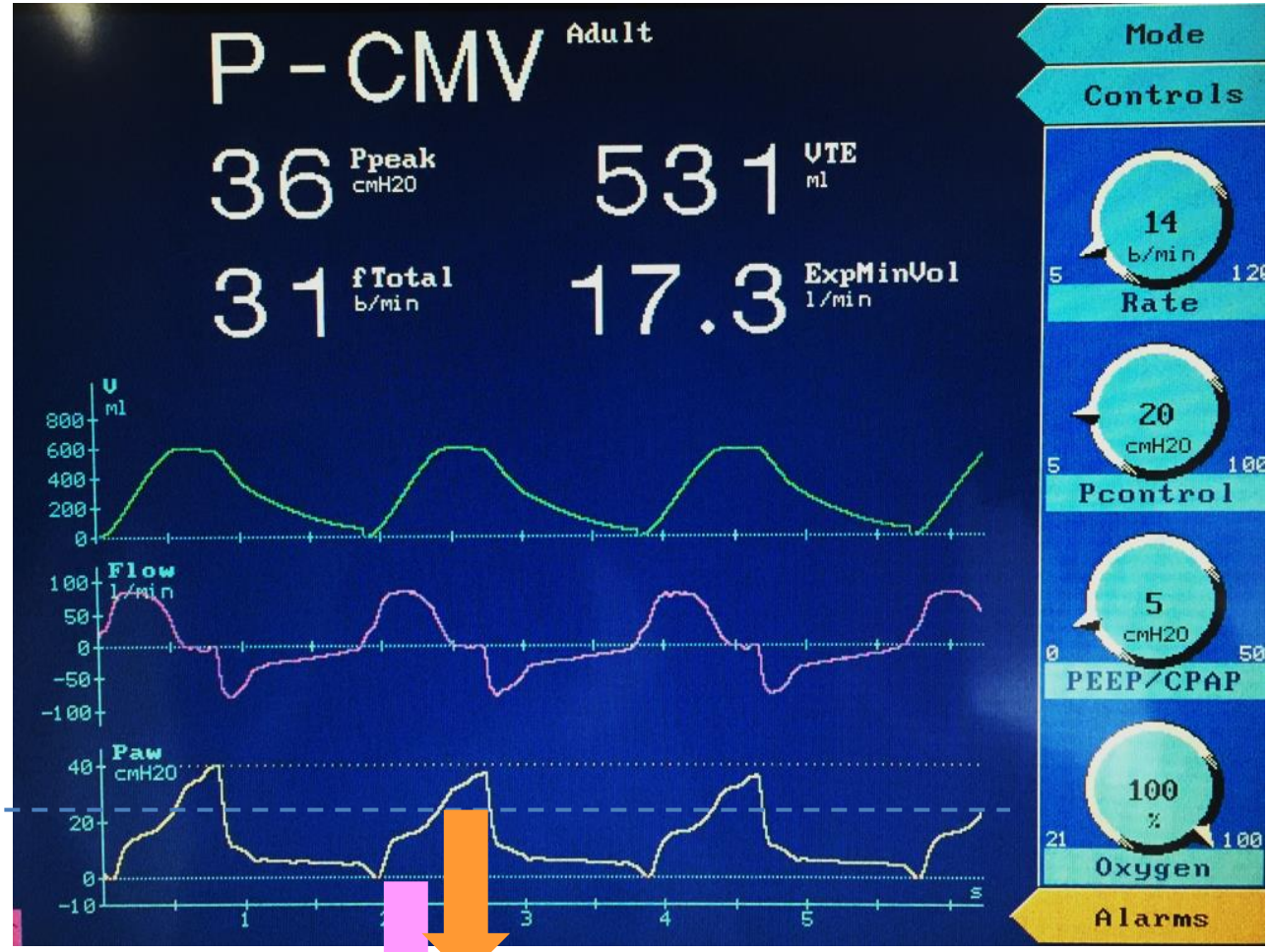


Solution:

- Shorten cycle criteria (volume, time, flow)
- Address depressed drive

Crit Care Clin 2018;34:325–341

Delayed Cycling



25 cmH_2O

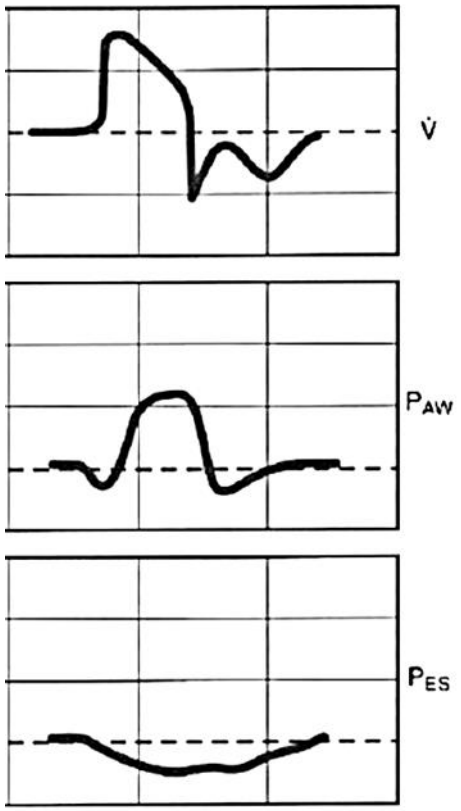
用力試圖吐氣

用力吸氣

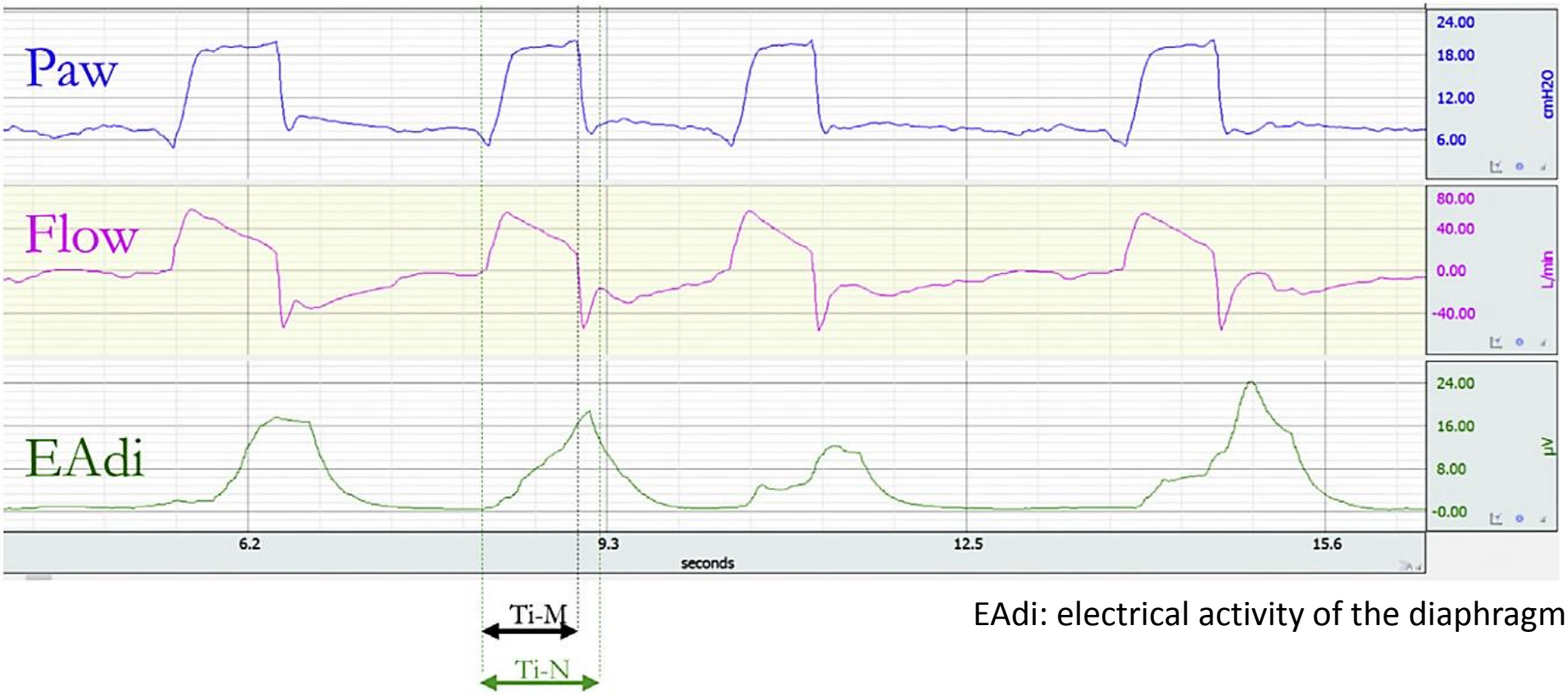
Neural T_I > Machine T_I

- Inappropriate high drive
  - Anxiety, pain, CNS abnormality...
- **Short (premature) cycling**
  - Air hungry during T_E
  - Hypoventilation
  - Double triggering
  - Breath stacking, higher V_T

    (ARDS patient)



Premature Cycling



EAdi: electrical activity of the diaphragm

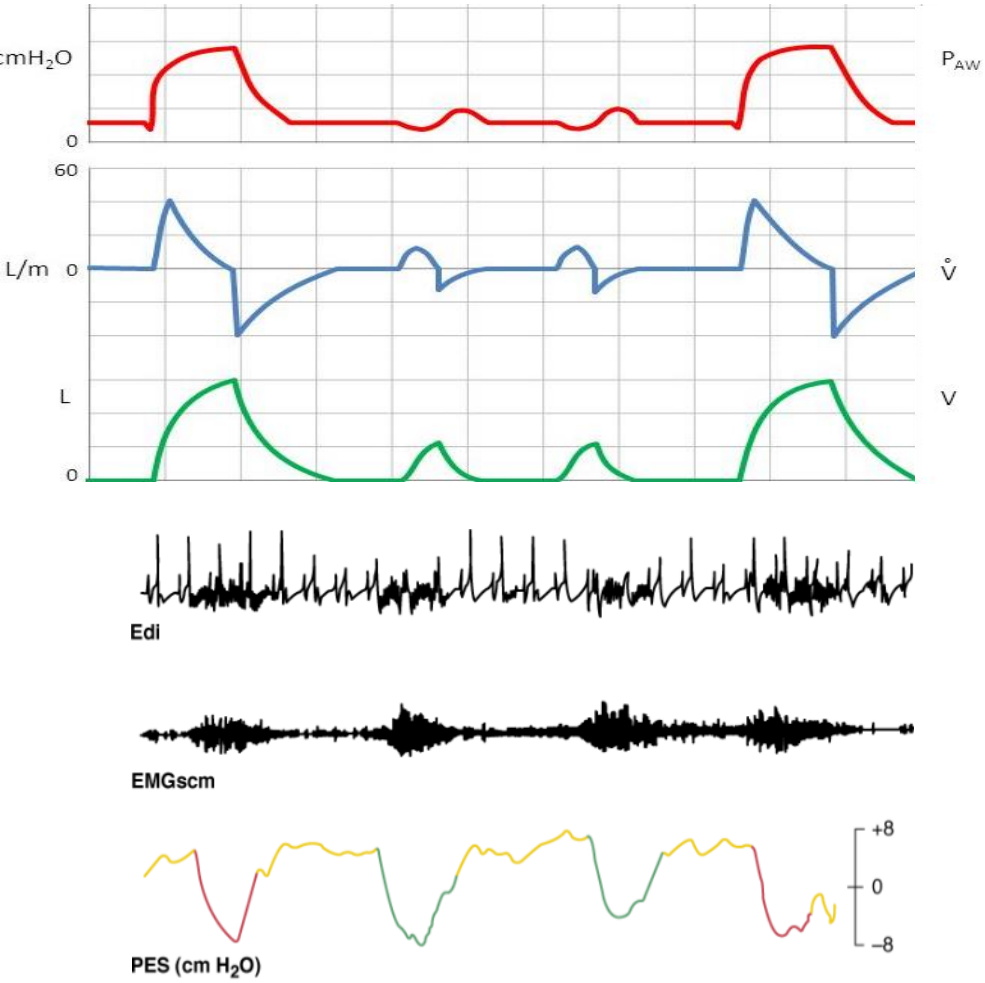
Solution:

- Lengthen cycle criteria (volume, time, flow)
- Address excessive drive

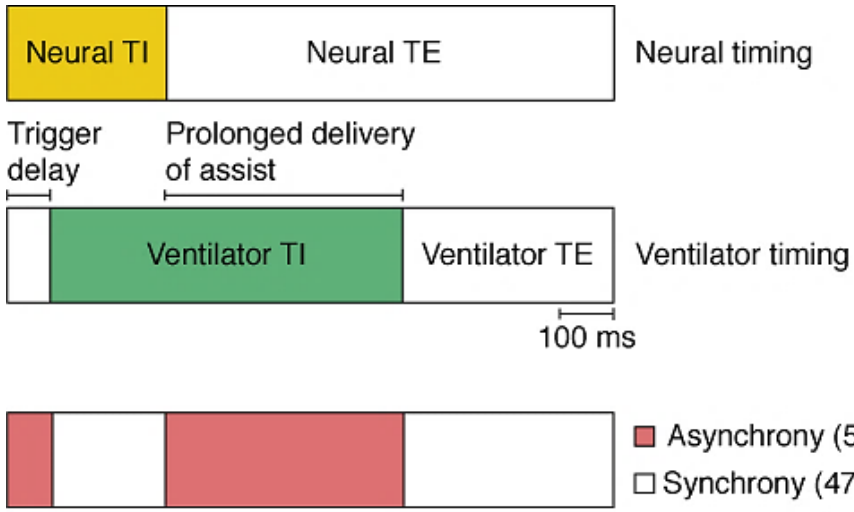
Crit Care Clin 2018;34:325–341

Effect of Multiple Breath Type

Synchronized Intermittent Mandatory Ventilation



More spontaneous breaths,
Less synchrony during the assisted mechanical breaths.



AJRCCM 2013;188: 1058-1068
Anesthesiology 1994;80:13-22
Pediatri Res. 2004;55:747-754
Am Rev Respir Dis 1988;138:1169-1179

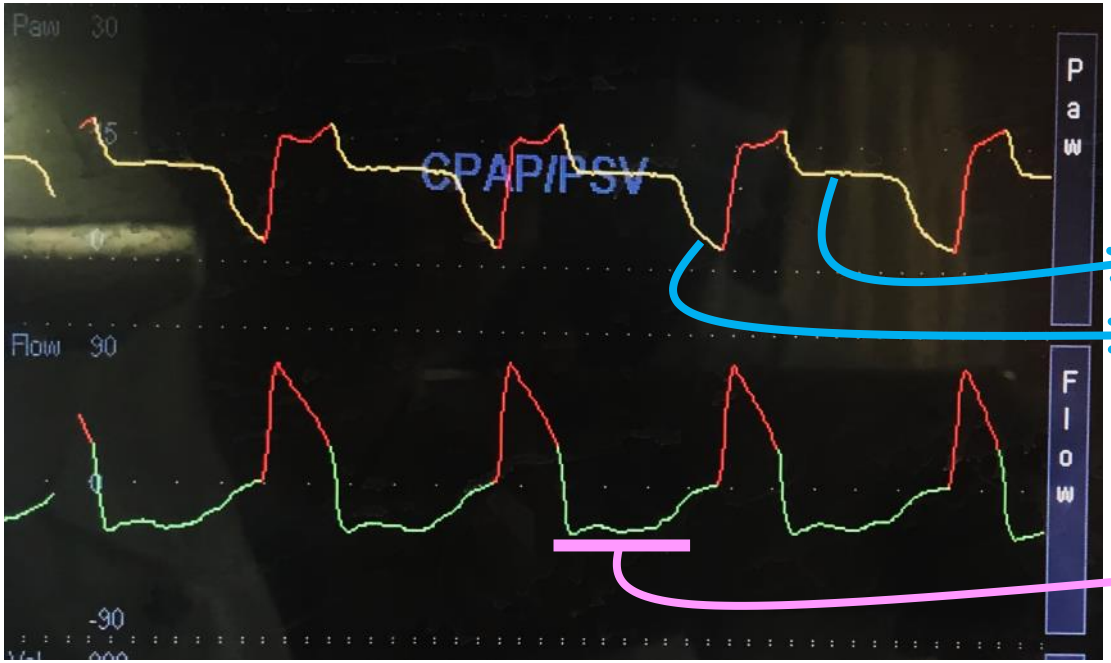
The Burden of Dyssynchrony

Main cohort studies looking at dyssynchrony

Author, Year	Chao et al,[7] 1997	Thille et al,[8] 2006	Pohlman et al,[22] 2008	de Wit et al,[38] 2009	Blanch et al,[11] 2015	Beitler et al,[21] 2016	Vaporidi et al,[39] 2017
Type of dyssynchrony	Ineffective efforts	Ineffective efforts Double-triggering Auto-triggering Short cycle Prolonged cycle	Double triggering	Ineffective efforts	Ineffective efforts Double-triggering Aborted Inspiration Short cycle Prolonged cycle Auto-triggering	Double-triggering	Ineffective efforts
Prevalence	11% had IE AI = 45 ± 13.8%	24% had AI >10% AI = 2.1% DT = 13% IE = 85%	Mean: 2.3 ± 3.5 DT per minute DT: 9.7% of breaths	27% had AI >10%	Median AI = 3.41% (IQR = 1.95–5.77)	DT = 27 breaths/h Hourly peak = 170 breaths/h At least one DT during 72% of hours recorded	AI = 2.43 [IQR 1.1–5.1] 12% had AI >10% 30.4% had clusters IE
Risk factors	IE: COPD, Higher age, higher $Paco_2$, lower MIP	DT: More sedated patients; Lower Pao_2 Fio_2 ratio; VCV/AC mode; shorter Ti; higher PEEP IE: Male gender; COPD; higher bicarbonates; alkalosis; higher PS and PIP; less sensitive trigger; higher VT	DT: Lower set VT	AI >10%: Pressure triggered breath and higher intrinsic respiratory rate	DT more frequent in PCV/AC and PSV IE: more frequent in PSV and with higher PS		Clusters of IE: more frequent in patients with sepsis
Outcome	IE associated with lower rate of weaning success (16% vs 57%)	AI >10% associated with longer MV and higher rate of tracheostomy		IE associated with longer duration of MV, longer ICU and Hospital stay	AI >10% associated with higher ICU and hospital mortality		Clusters of IE in the 1st recording associated with longer duration of MV and higher mortality

Crit Care Clin 2018;34:325-341

Other Situations (Cases)



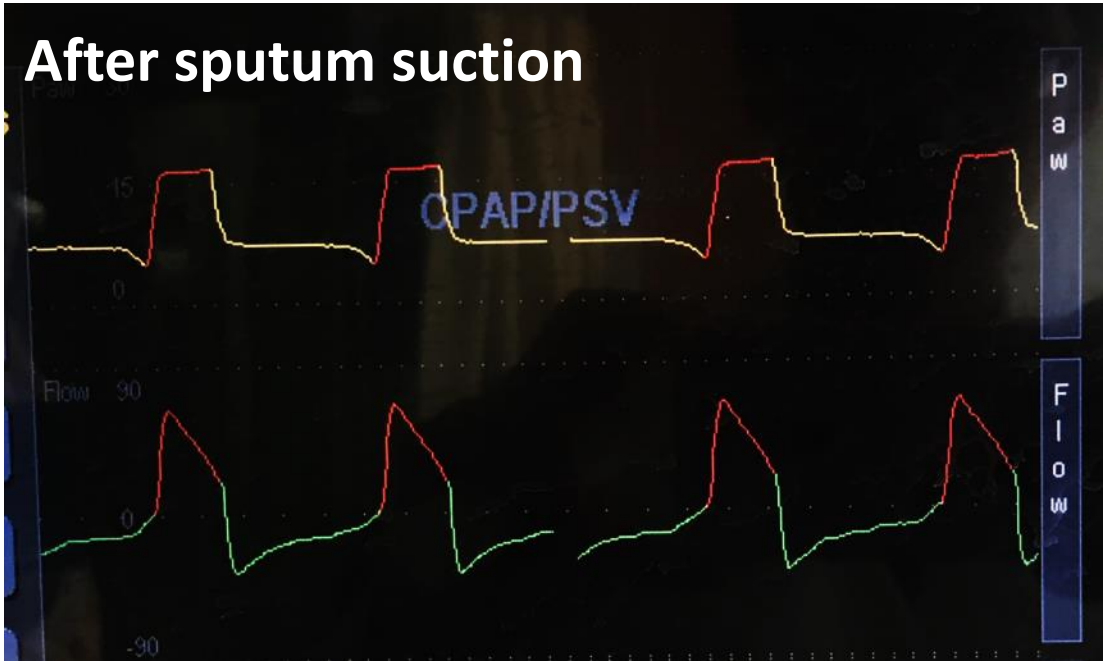
Problem: 吸吐費力

Set PEEP 7, Psupp 10 cm H_2O

Measured PEEP 13 cmH_2O

Significant effort to trigger a breath

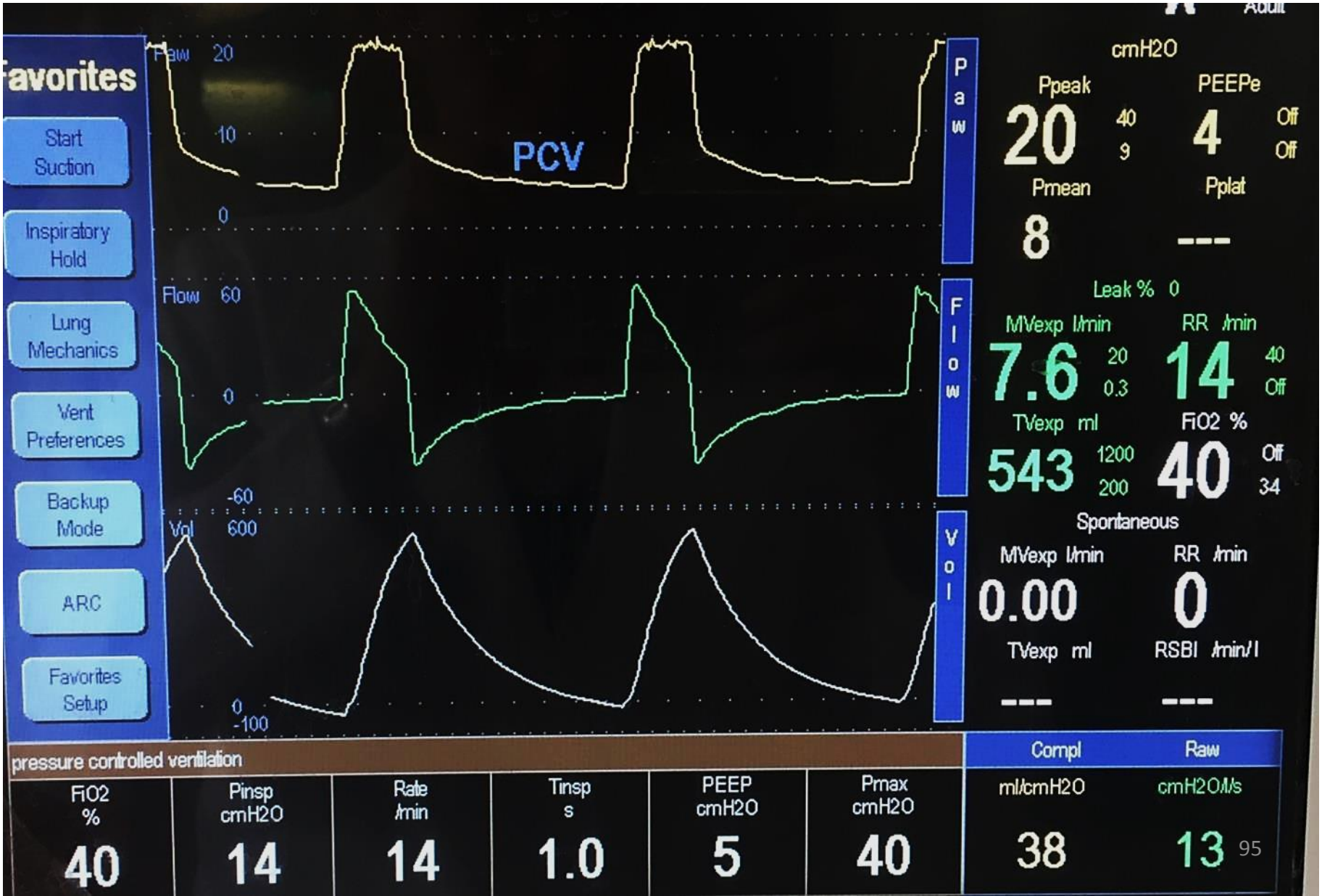
Expiratory flow limitation

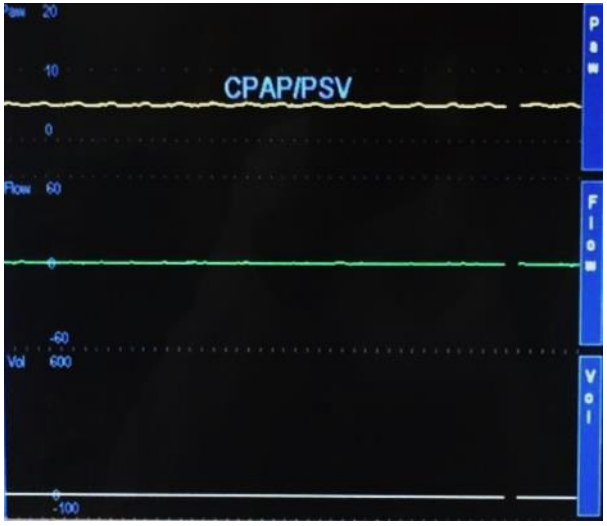


Variable obstruction of large airway

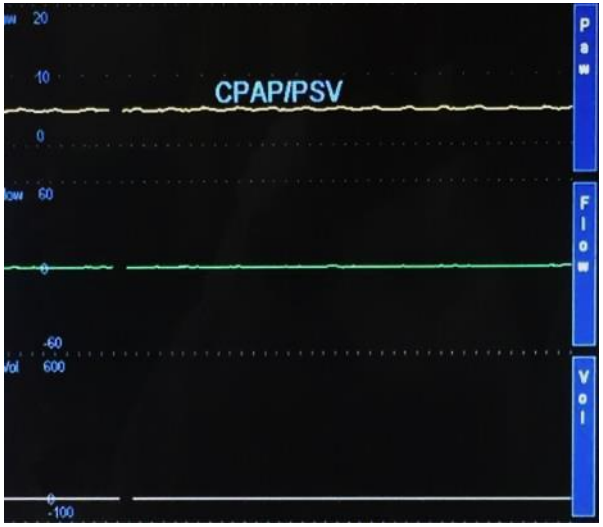
90 y/o male, BW 50 Kg Bronchopneumonia (sputum impaction)

CXR improved after chest care. **Weaning failure due to apnea.**

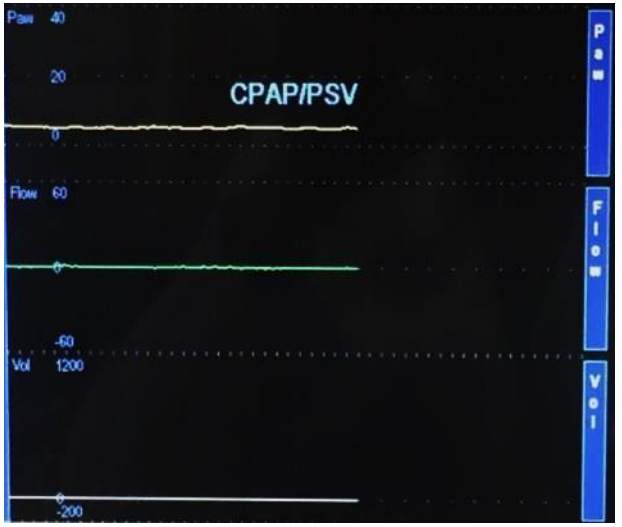




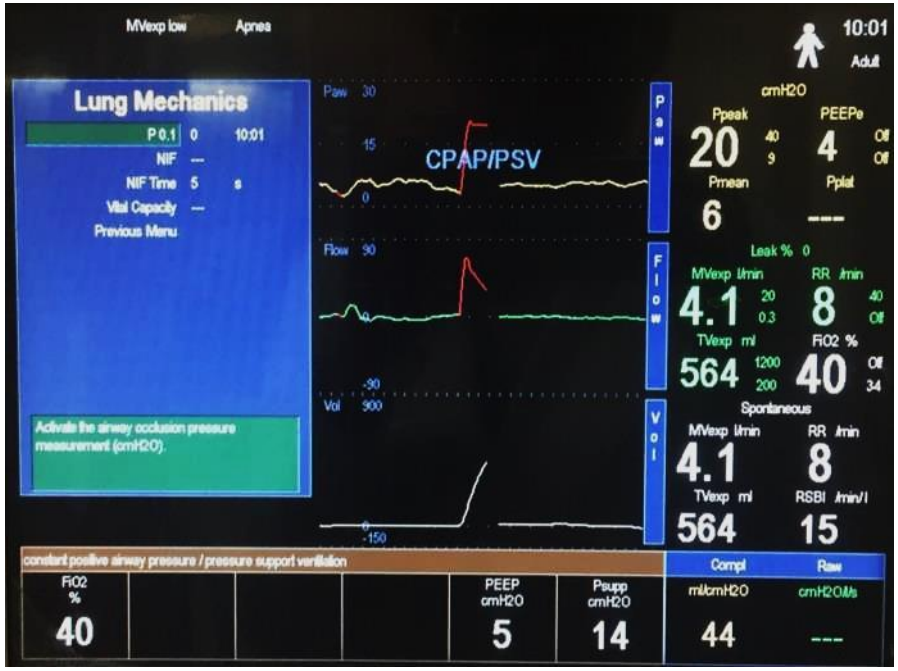
第20秒



第60秒



第90秒



2分鐘後

10分鐘後

57 y/o
AECOPD

名稱/值	1061211	1061211	1061210	1061210	1061210	1061210	1061210
pH	7.202	7.352	7.270	7.332	7.258	7.247	7.202
pCO2	93.2	58.2	76.1	63.7	75.9	77.9	89.7
pO2	61.6	171.9	45.2	213.0	92.9	115.1	91.1
HCO3	35.7	31.5	34.2	33.0	33.1	33.2	34.4
TCO2	38.6	33.3	36.5	35.0	35.5	35.6	37.2
ABE	3.3	4.4	3.6	5.0	3.1	2.9	2.5
BEecf	7.7	5.9	7.3	7.1	6.1	5.9	6.4
SBC	26.4	27.4	27.1	27.8	26.2	26.0	25.6
O2 sat.	85.1	99.5	74.5	99.7	95.7	97.6	94.6

$\pi r^2 \cdot 35\ cm$
$= 105$ ml
Dead space

ABG 30 minutes after RSI (Rapid Sequence Intubation) (Midazolam 5 mg + Rocuronium 50 mg)

❶66 y/o female, DKA

pH	7.117		6.980
pCO2	14.3		36.7
pO2	109.9		96.7
HCO3	4.5		8.4
TCO2	5.0		9.6
ABE	-23.2		-23.9
BEecf	-24.9		-23.2
SBC	7.6		8.7
O2 sat.	94.9		89.2

❷55 y/o male, AKI on CKD During emergent HD

pH	7.317		6.984
pCO2	16.8		71.5
pO2	111.4		362.6
HCO3	8.4		16.6
TCO2	8.9		18.8
ABE	-14.8		-17.1
BEecf	-17.8		-14.9
SBC	12.5		12.4
O2 sat.	97.5		99.8

❸45 y/o male, Cirrhosis, pneumonia

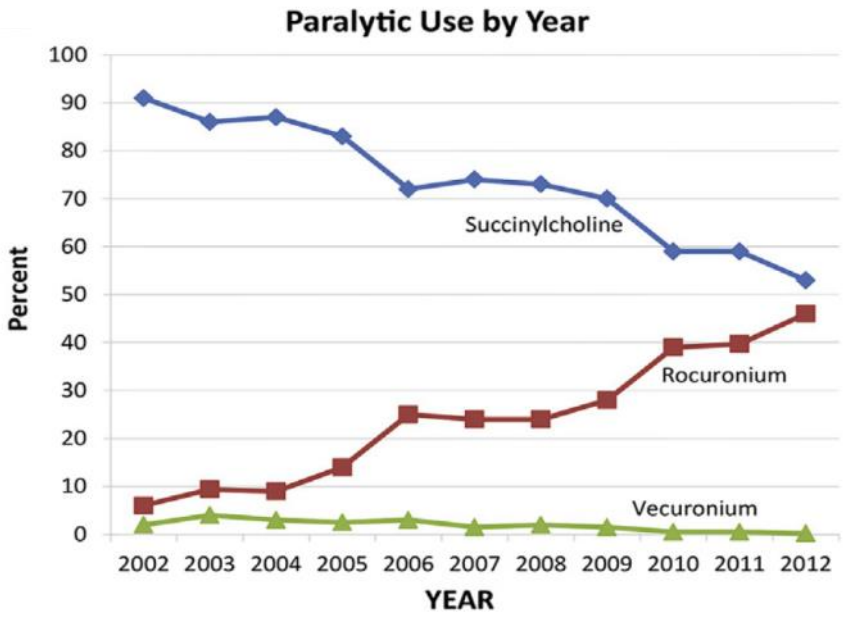
pH	7.188		6.946
pCO2	37.4		62.1
pO2	70.4		93.8
HCO3	13.9		13.2
TCO2	15.1		15.1
ABE	-14.2		-21.2
BEecf	-14.3		-19.0
SBC	14.1		10.4
O2 sat.	87.4		87.4

❹50 y/o male, Change of consciousness

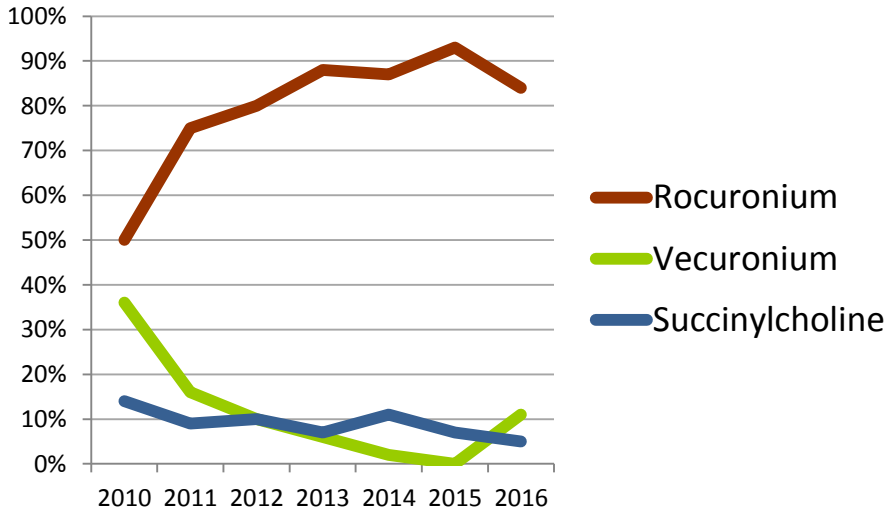
pH	7.475		6.810
pCO2	18.1		66.3
pO2	196.2		41.8
HCO3	13.0		10.3
TCO2	13.6		12.4
ABE	-6.8		-28.7
BEecf	-10.6		-24.0
SBC	17.9		7.7
O2 sat.	99.7		31.8

The Increasing Use of Rocuronium in RSI

USA, Canada, Australia



Japan



Ann Emerg Med. 2015;65:363-370.
Resuscitation 2017;114:14-20.

Neuromuscular Blockade	Onset	Duration
Rocuronium	1-1.6 m	**22-94 m***
Succinylcholine	0.5-1 m	6~10 m

*Rocuronium於肝腎功能差者，作用時間可達**數小時**

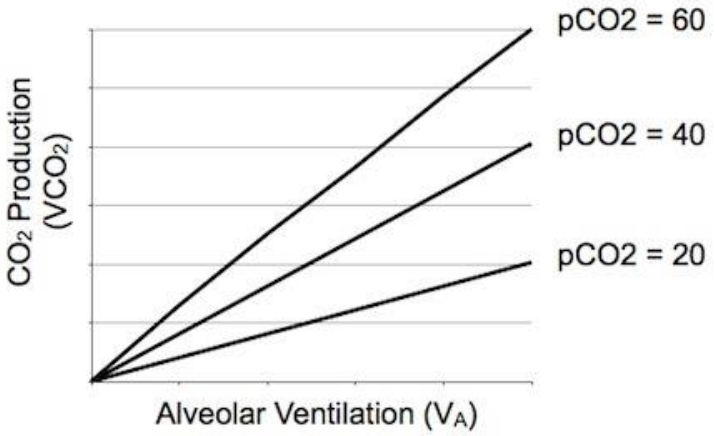
Metabolic acidosis with
(Spontaneous)
Kussmaul breathing
~**RR 26/min, MV 18 L/min**

↓ RSI

Paralyzed
Mechanical breathing, V_T 0.5 L/min,
RR 14/min, MV 7 L/min

↓

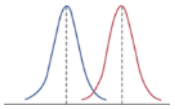
Combined metabolic and Respiratory acidosis

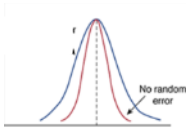


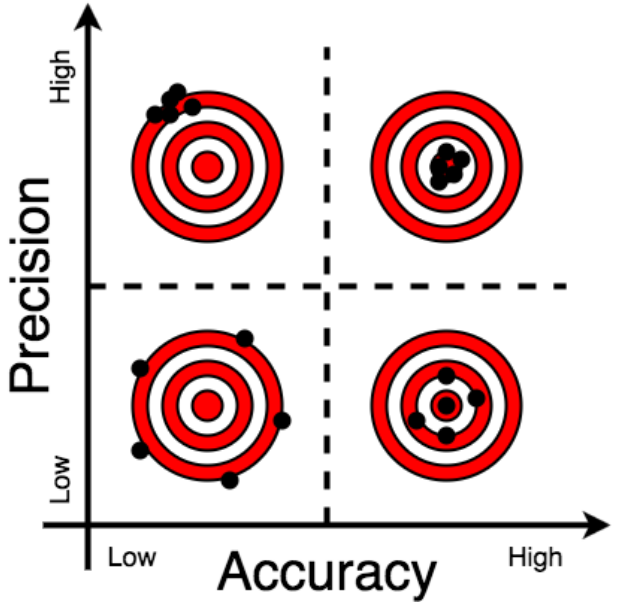
代謝性酸中毒病人RSI使用非去極化神經肌肉阻斷劑，呼吸器起始設定RR可參考插管前病患狀態，並密切監控ABG & Vital signs

Take Home Message - 1

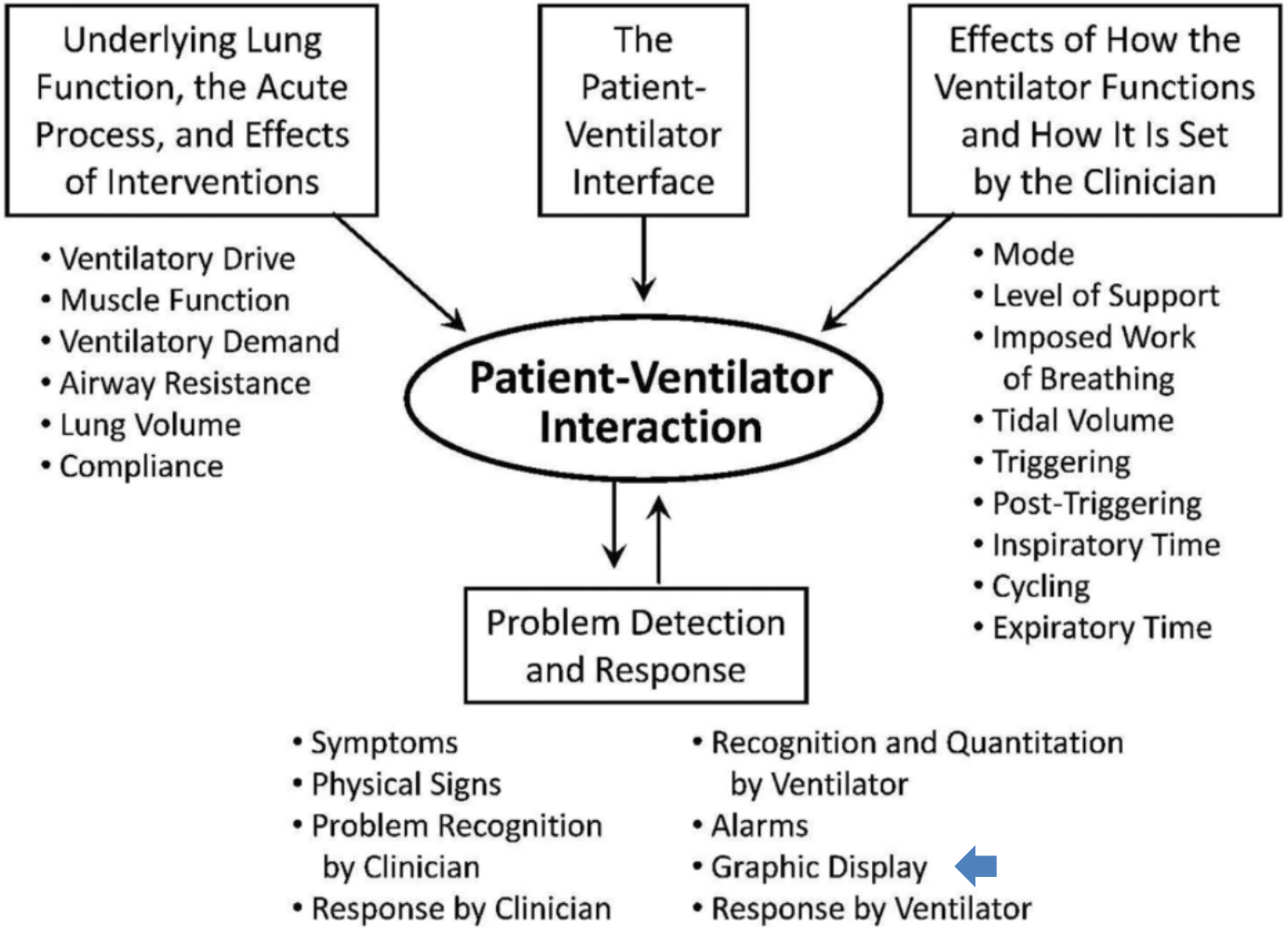
- Fundamentals of measurement Theory
  - Accuracy and Systemic error
  - Precision and Random error
  - Linearity
  - Calibration







Take Home Message - 2



Respiratory Care 2011;56:214-228

Type of Dyssynchrony	Possible Solution	Specific Clinical Characteristics
Triggering phase		
Delayed/missed triggers		
Insensitive system	↑Sensitivity	
PEEPi	Reduce PEEPi	
Extratriggering		
Autocycling	↓Sensitivity	
Reverse triggering	↓Controlled breath	
Double triggering	↑Cycle criteria (volume, time, flow)	
Flow delivery phase		
Inadequate flow	↑Flow, change pattern, use pressure targeting	
	Address excessive drive	
Excessive flow		
Cycling phase		
Neural T_I > machine T_I	↑Cycle criteria	
	Address excessive drive	
Machine T_I > neural T_I	↓Cycle criteria	
	Address depressed drive	

AJRCCM 2013;188: 1058-1068

感恩

Thank you very much!