Ventilator dys-synchrony physiology and its management

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Outline

- Physiology – work of breathing, Equation, physiology of patient initiated mechanical breath
- Dys-synchrony, classification, prevalence, Effects of PV dys-synchrony
- ICU outcomes
- Diagnosis methods
- Individual dys-synchronies and types, detection in scalars, Poes, Edi and along with the management
- Modes of ventilation and occurrence of asynchrony

Why PV dys-synchrony is important?

- Mechanical ventilation if does not meet the patient's demand becomes a double edged sword
- Causes increased workload, discomfort, impairment of gas exchange, diaphragmatic and lung injury
- Lead to increased duration of mechanical ventilation, increased length of hospital and ICU stay, morbidity and mortality
- Dyssynchrony can be either due to inappropriate patient's ventilatory drive or suboptimal ventilator settings

Zhou Y et al, Etiology, incidence, and outcomes of patient-ventilator asynchrony in critically-ill patients undergoing invasive mechanical ventilation. Sci Rep. 2021 Jun 11;11(1):12390.

Role of respiratory muscles in patient ventilator interactions in ICU

- Too much load on the respiratory muscles lead to muscle damage
- Too much assistance lead to respiratory muscles weakness and atrophy
- Electrolyte imbalance, sepsis, hyperglycaemia, usage of neuromuscular agents also contribute to the muscle weakness in ICU

Physiology of patient initiated mechanical breath

- Triggering phase
- Post triggering phase – a) variable controlling the flow or pressure b) cycling off variable

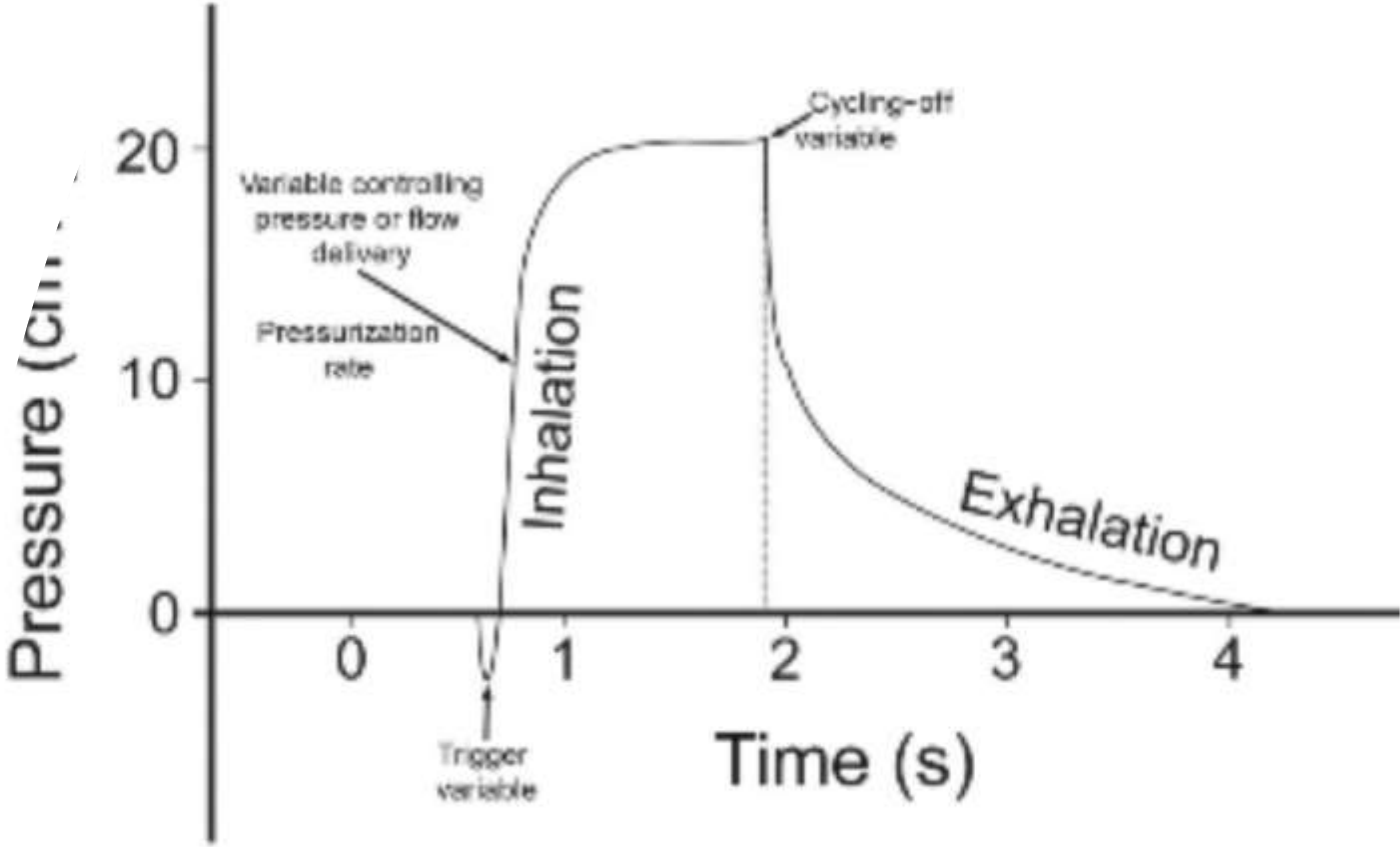
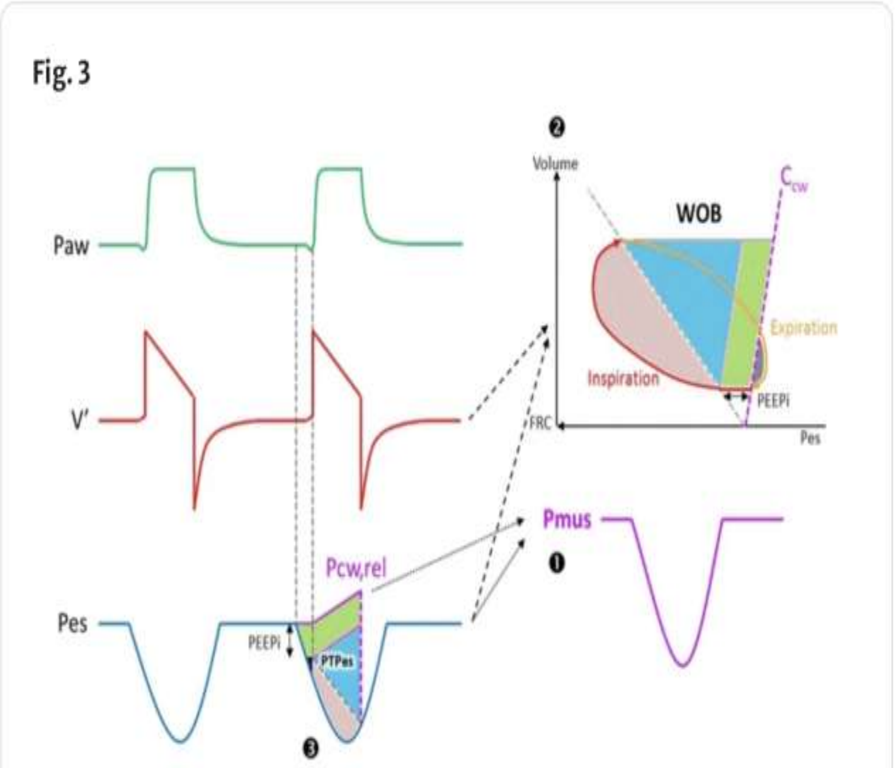


Fig. 2. Components of a patient-triggered mechanical breat
triggering phase comprises the trigger variable. The post-tri
ing phase consists of the variable controlling pressure o
delivery and the cycling-off variable. In pressure-control ve
ion, the pressurization rate determines flow delivery, while in
ycled pressure-control ventilation the cycling-off variable
nes mechanical inspiratory time.

Sassoon CSh. Triggering of the ventilator in patient-ventilator interactions. Respir Care. 2011 Jan;56(1):39-51.

Triggering phase

- Trigger time delay – onset of patient effort to onset of flow delivery
- Pressure-time product of the inspiratory muscles is the patient effort during triggering (PTPtrig) and is relatively constant with different levels of ventilatory support
- The percentage change from total inspiratory effort in PTPtrig at different levels of pressure support is small
- Ideal response time to patient inspiratory trigger should be <100 ms



Sassoon CSh. Triggering of the ventilator in patient-ventilator interactions. Respir Care. 2011 Jan;56(1):39-51.

Variable controlling flow or pressure delivery

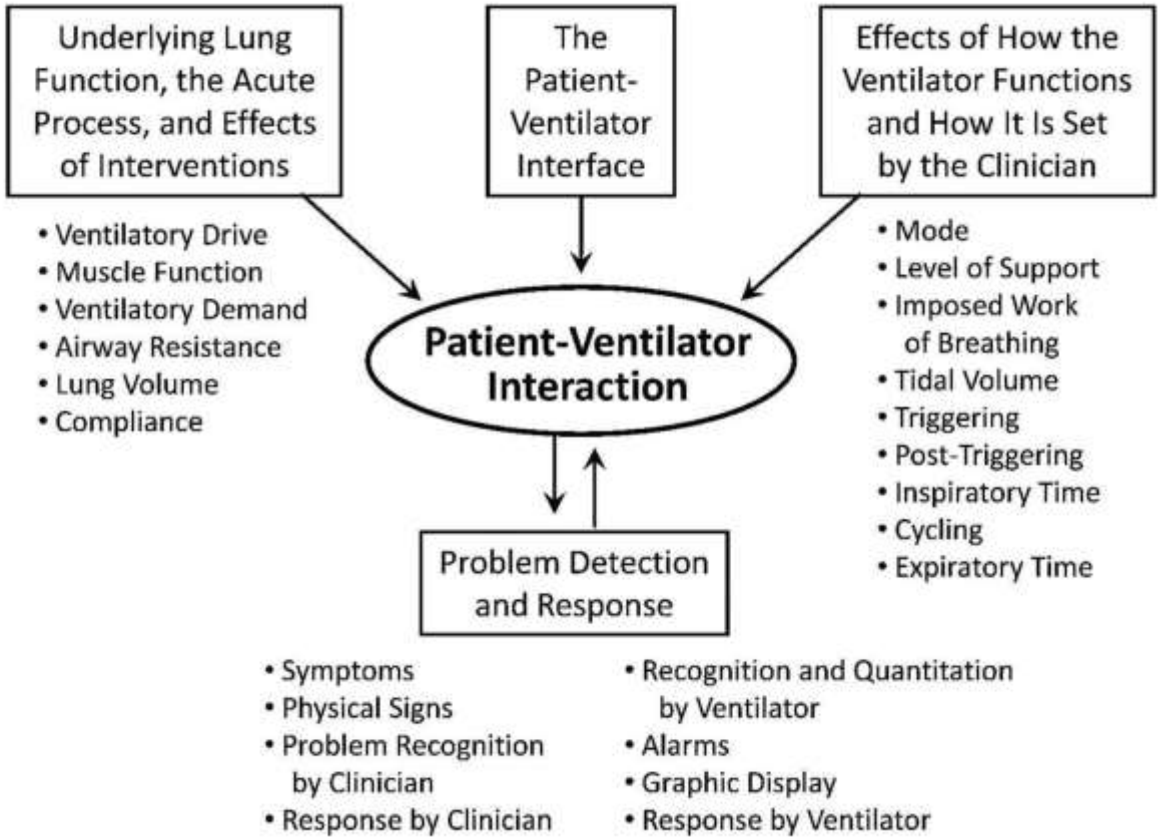
- In pressure support mode, flow delivery is controlled by the pressurisation rate (Pramp)
- In volume control mode, flow delivery is controlled by the flow rate and shape of the flow
- Too low pressurisation rate or low flow rate, leads to air hunger
- Too high pressurisation rate or high flow rate leads to patient discomfort
- Therefore optimal pressurisation rate or flow rate has to be set to unload the inspiratory muscles

Cycling off variable

- The cycling of a mechanical ventilator breath occurs after a set value is reached. These values are often referred to as "cycle variables"
- Cycling off variable can be pressure, time, volume or flow cycled
- Fixed cycling threshold does not meet varying patient's respiratory mechanics
- Acute lung injury – eg: ARDS. Expiratory time constant is short, the inspiratory muscle work load is mainly unloaded by the pressurisation rate. Cycling off variable did not have much role in reducing work load where expiratory time constant is short
- Obstructive lung diseases – eg: COPD. The expiratory time constant is prolonged. Cycling off variable have significant role in unloading the inspiratory muscles work load. However at higher pressure support, high cycling off variable did not have much influence on work load of inspiratory muscles

Gentile MA. Cycling of the mechanical ventilator breath. Respir Care. 2011 Jan;56(1):52-60

Physiology of patient-ventilator interaction



- When the delivery of gas by the ventilator does not correspond in quantity, timing, or pattern to what the patient wants, PVA is the result
- Its manifestations include excessive work of breathing and when the mismatch between patient demand and ventilator delivery is severe, the result is respiratory distress and “fighting the ventilator,”

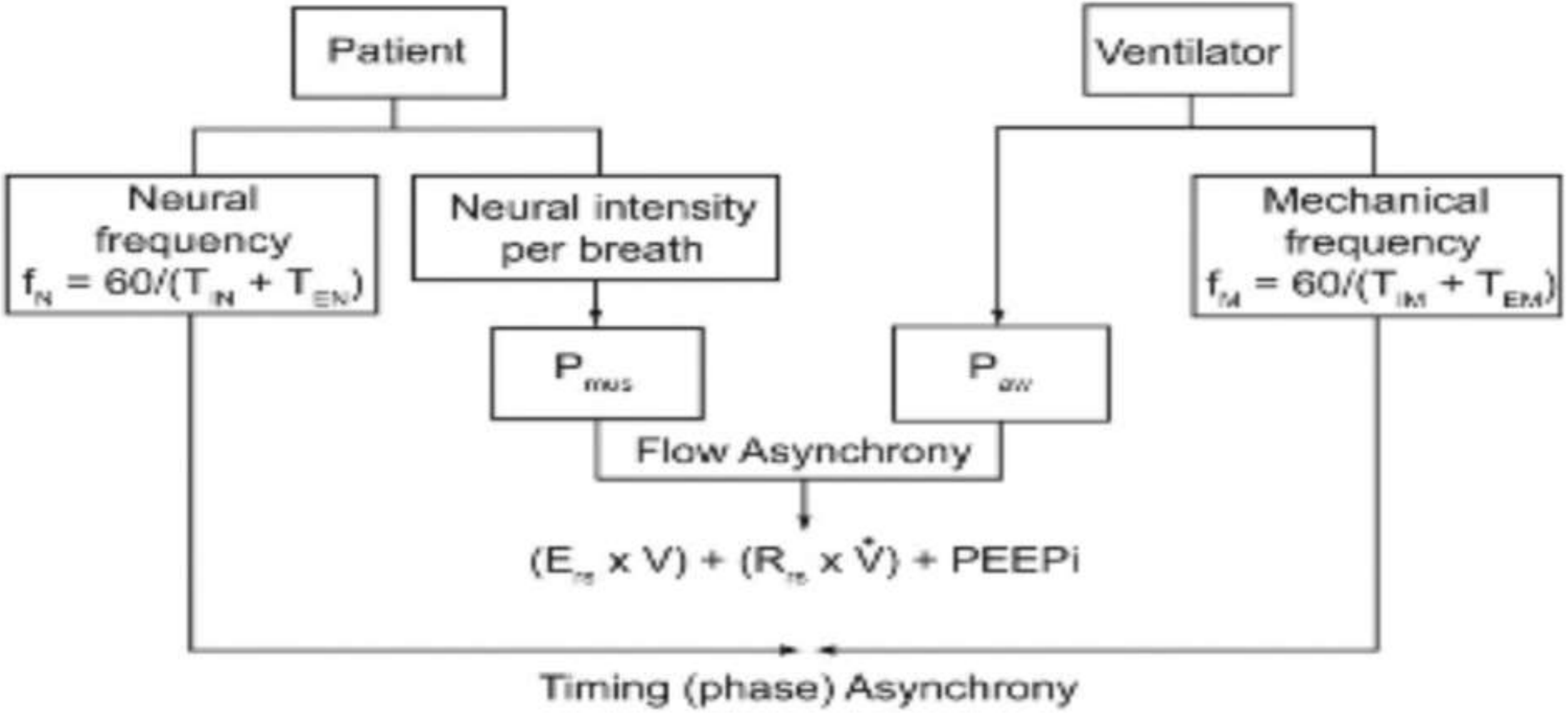
Equation of motion for the respiratory system

$$P_{vent} = P_{elastic} + P_{resistive}$$

$$P_{vent} = \text{Elastance} \times \text{Volume} + \text{Resistance} \times \text{Flow}$$

- Pelastic denotes elastic forces of the lung and chest wall
- Presistive denotes the resistive pressure of the lung
- For patient-ventilator synchrony to be maintained, the sum of these components has to balance the resistive and elastic loads

Patho-physiology of PV dysynchrony



Sassoon CSh. Triggering of the ventilator in patient-ventilator interactions. Respir Care. 2011 Jan;56(1):39-51.

Clinically significant PVA

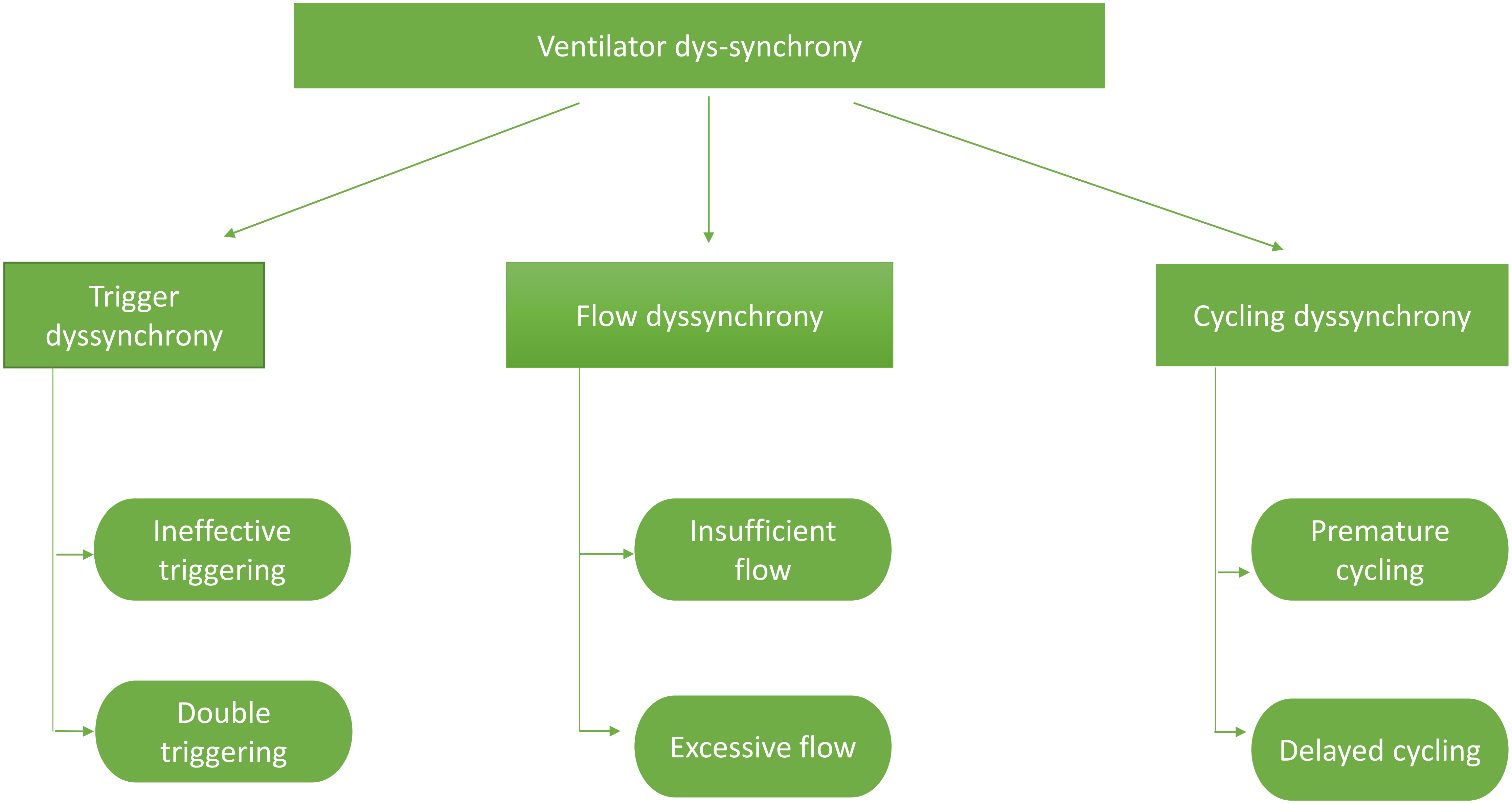
- >10% of breaths which are asynchronous are considered clinically significant
- Asynchrony index – (total number of asynchrony events /total number of neural breaths (both delivered and ineffective breaths)) * 100

Dys-synchrony

- Ventilator dyssynchrony is defined as the inappropriate timing and delivery of a mechanical breath in response to patient effort
- Classification:

➢ Trigger dys-synchrony
➢ Flow dys-synchrony
➢ Cycling dys-synchrony

Sottile PD et al., Ventilator dyssynchrony - Detection, pathophysiology, and clinical relevance: A Narrative review. Ann Thorac Med. 2020 Oct-Dec;15(4):190-198.


Ventilator dys-synchrony
Trigger dyssynchrony
Flow dyssynchrony
Cycling dyssynchrony
Ineffective triggering
Double triggering
Insufficient flow
Excessive flow
Premature cycling
Delayed cycling

Prevalence

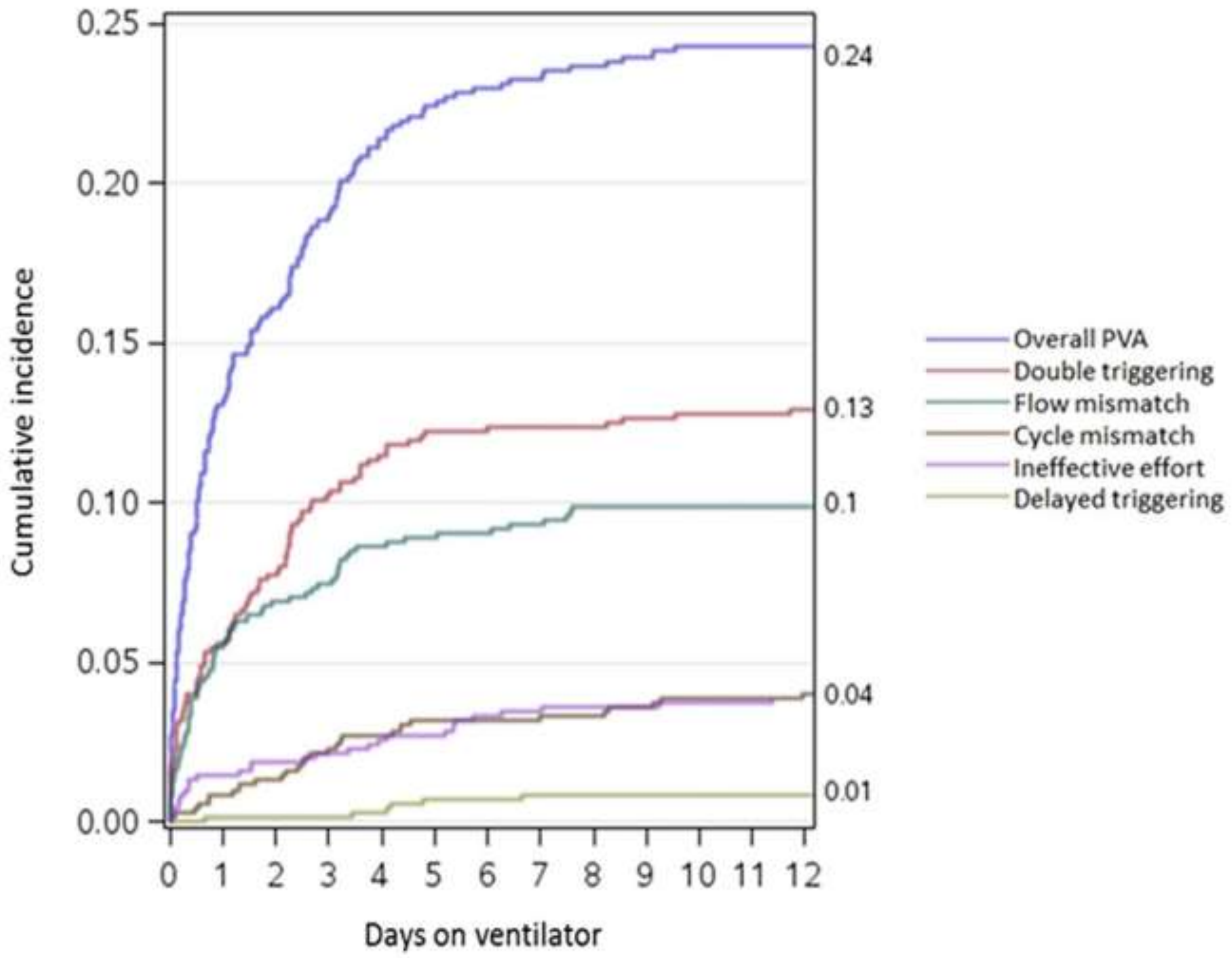


Figure1. Cumulative incidence of asynchrony over the first 12 days of mechanical ventilation.

- Retrospective cohort study
- 670 patients underwent 696 MV episodes
- Overall incidence - 24%
- Double triggering (13%)>flow starvation(10%)
- Volume control ventilation > pressure control ventilation

Zhou Y et al, Etiology, incidence, and outcomes of patient-ventilator asynchrony in critically-ill patients undergoing invasive mechanical ventilation. Sci Rep. 2021 Jun 11;11(1):12390.

Table 1: Frequency of ventilator dyssynchrony in reported literature

Author	Patient type	Mode of ventilation	Types of VD	Frequency (%)
Fabry 1996	Respiratory failure 5 min samples 11 patients	IPS	IEE	20.0 (0.0-40)
Thille 2006	Respiratory failure 30 min samples 62 patients	Any	All	2.1 (0.7-8.6)
		VCV	All	4.3±4.8
			IEE	3.0±4.9
			Double triggered	1.2±2.3
		PSV	All	1.9±3.8
			IEE	1.8±3.7
			Doubled triggered	0.1±0.4
Pohlman 2008	ARDS 5 min samples 20 patients	VCV	Double triggered	9.7±15.2
De Wit 2009	Respiratory failure 15 min samples 35 observations	Any	All	11±14
			IEE	9±12
			Double triggered	5.8
			Short cycled	5.6
Mellot 2014	Respiratory failure 90 min samples 30 patients	Any	All	23.3
			IEE	14.7
			Double triggered	0.17
			Flow limited	0.20
			Premature cycling	2.14
			Delayed cycling	0.02
Blanch 2015	Respiratory failure Continuous samples 50 patients	Any	All	3.41 (1.95-5.77)
		VCV	All	1.49 (0.32-4.68)
			IEE	0.91 (0.15-3.36)
			Double triggered	0.06 (0.00-0.29)
		PCV	All	1.69 (0.54-4.37)
			IEE	0.98 (0.23-3.32)
			Double triggered	0.11 (0.00-0.44)
		PSV	All	2.15 (0.90-4.74)
			IEE	1.18 (0.49-2.96)
			Double triggered	0.12 (0.00-0.32)
Sottile 2018	Acute hypoxic respiratory failure Continuous samples 62 patients	APVCMV/PCV	All	34.4 (34.4-34.5)
			IEE	24.8 (24.2-25.0)
			Double triggered	3.12 (3.1-3.14)
			Flow limited	13.6 (13.56-13.64)

The measured frequency of all ventilator dyssynchrony and specific sub-types of ventilator dyssynchrony in the landmark studies today, as a function of ventilator mode. IPS=Inspiratory pressure support, VCV=Volume-controlled ventilation, PCV=Pressure-controlled ventilation, PSV=Pressure support ventilation, APVCMV=Adaptive pressure ventilation continuous mandatory ventilation

Most common is ineffective efforts

Adverse effects of patient ventilator dys-synchrony

- Hypoxemia
- Lung over-distension
- Dynamic hyperinflation
- Increased work of breathing
- Patient discomfort
- Excessive administration of sedatives and NM blockers
- Respiratory muscle dysfunction
- Prolongation of mechanical ventilation
- Neuromuscular complications due to prolonged immobility

Effect on ICU outcome

- Long duration of mechanical ventilation (MD – 5.6 days)
- Higher ICU mortality (OR – 2.73)
- Higher hospital mortality (OR – 1.94)
- Higher incidence of tracheostomy (OR – 2.13)
- Delays weaning
- Higher re-intubation rates

Kyo M et al., Patient-ventilator asynchrony, impact on clinical outcomes and effectiveness of interventions: a systematic review and meta-analysis. J Intensive Care. 2021 Aug 16;9(1):50.
Zedan, M et al., A. Study of Patient Ventilator Dyssynchrony, Causes and Effect on Weaning in Mechanically Ventilated Patient in Respiratory Intensive Care Unit, Observational Study. The Egyptian Journal of Hospital Medicine, 2019; 74(5): 1031-1035.

Diagnosis methods:

- ➢ Ventilator waveform analysis – Scalars
- ➢ Oesophageal pressure monitoring
- ➢ Electrical diaphragmatic activity
- ➢ Automatic software algorithm

Chart 1. Factors that affect the occurrence and detection of patient-ventilator asynchrony.

Factors related to the occurrence of asynchrony	Factors related to the detection of asynchrony
Indication for MV	Observation time
Severity of respiratory failure	Length of the observation periods
Ventilatory modes	Timing of observation during MV (e.g., first days and phase of weaning)
Ventilator settings	Detection method (e.g., clinical assessment, waveform monitoring, esophageal balloon measurement, and detection of the electrical activity of the diaphragm)
Level of sedation	Definition of asynchrony and of its significance

MV: mechanical ventilation.

J Bras Pneumol. 2018 Jul-Aug; 44(4): 321–333.

Trigger dys-synchronies

- Types:

✓ Ineffective trigger efforts (missed trigger, delayed trigger)

✓ Double trigger (DT – P , DT – V, DT – A)

- Best response time to trigger effort should be < 100 ms

Ineffective trigger - causes

- Triggering phase – trigger sensitivity, Neuromuscular weakness, dynamic hyperinflation(Auto PEEP), conditions suppressing respiratory drive like metabolic or respiratory alkalosis, blunted respiratory drive due to central causes
- Post triggering phase – higher level of ventilatory assistance (high tidal volume, high Ti —> hyperinflation—> autoPEEP), cycling threshold
- Most commonly due to auto-PEEP. Most commonly occurs in COPD and obstructive diseases

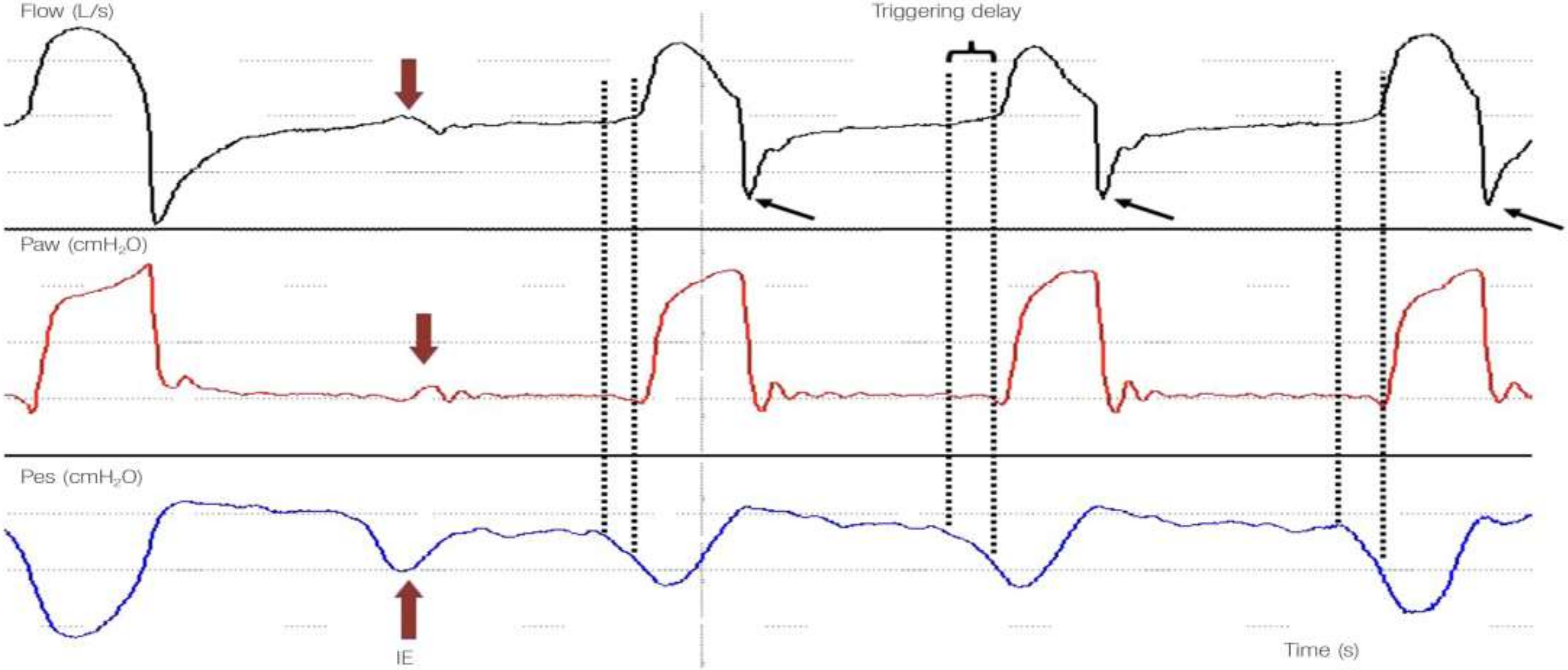
- Factors causing auto PEEP:

- ➢ Increased inspiratory time constant – large tidal volume
- ➢ Prolonged expiratory time constant – bronchoconstriction, obstructive diseases
- ➢ Shortened expiratory time – higher respiratory rate

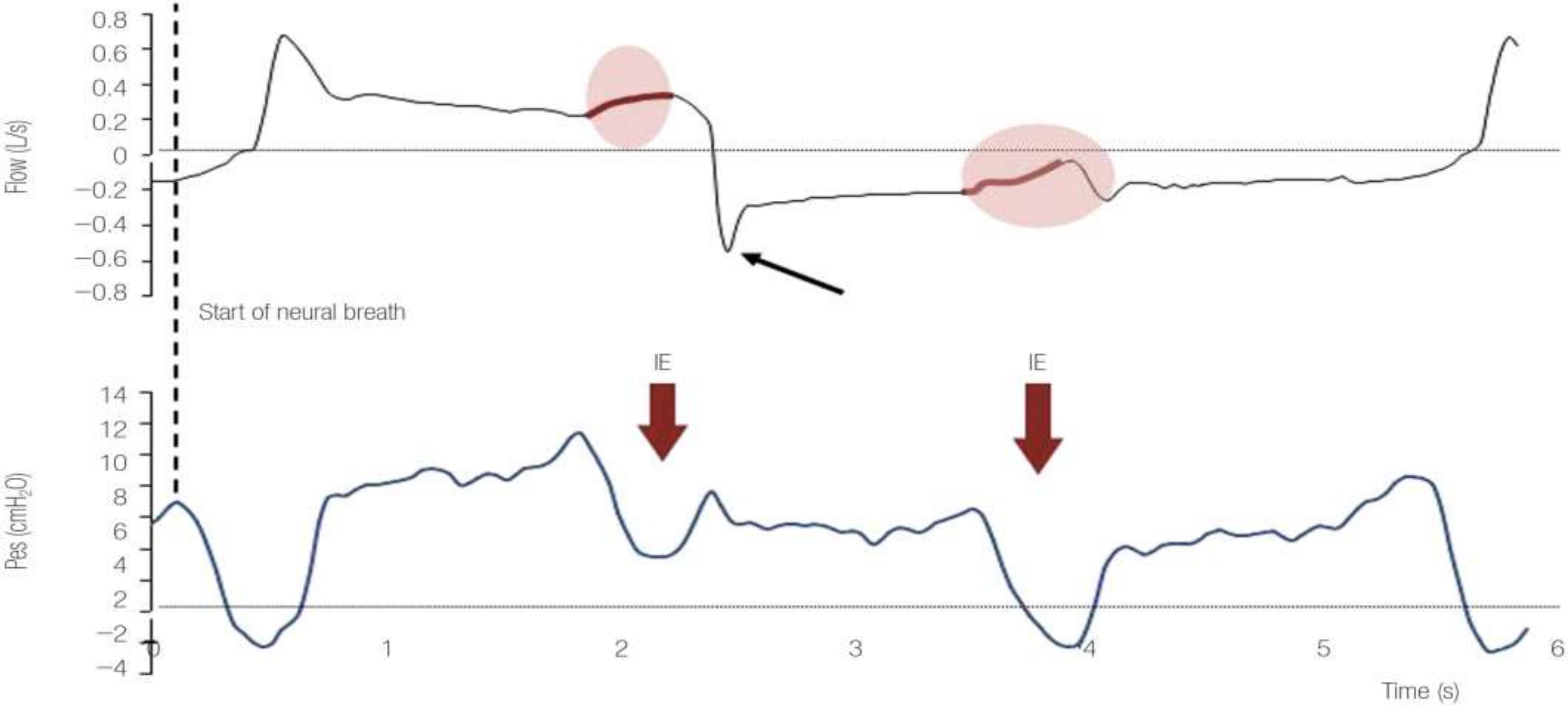
- Consequence of auto PEEP:

- ➢ Hypotension
- ➢ VILI
- ➢ PV asynchrony
- ➢ Increased dead space

Ineffective trigger and delayed trigger



Ineffective efforts



Ineffective efforts during expiration

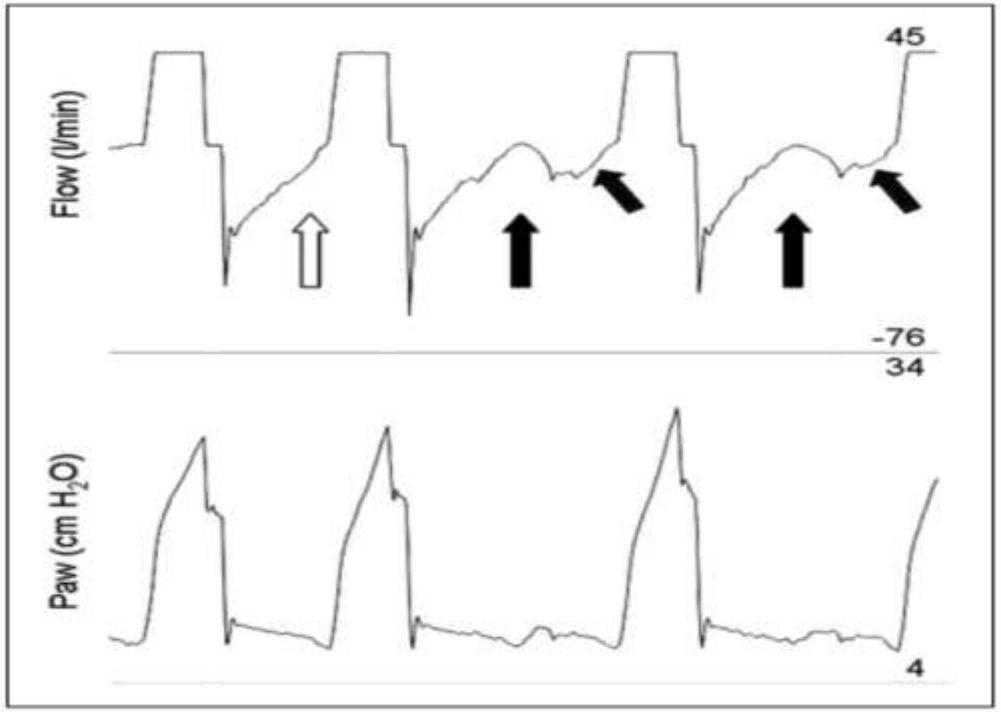


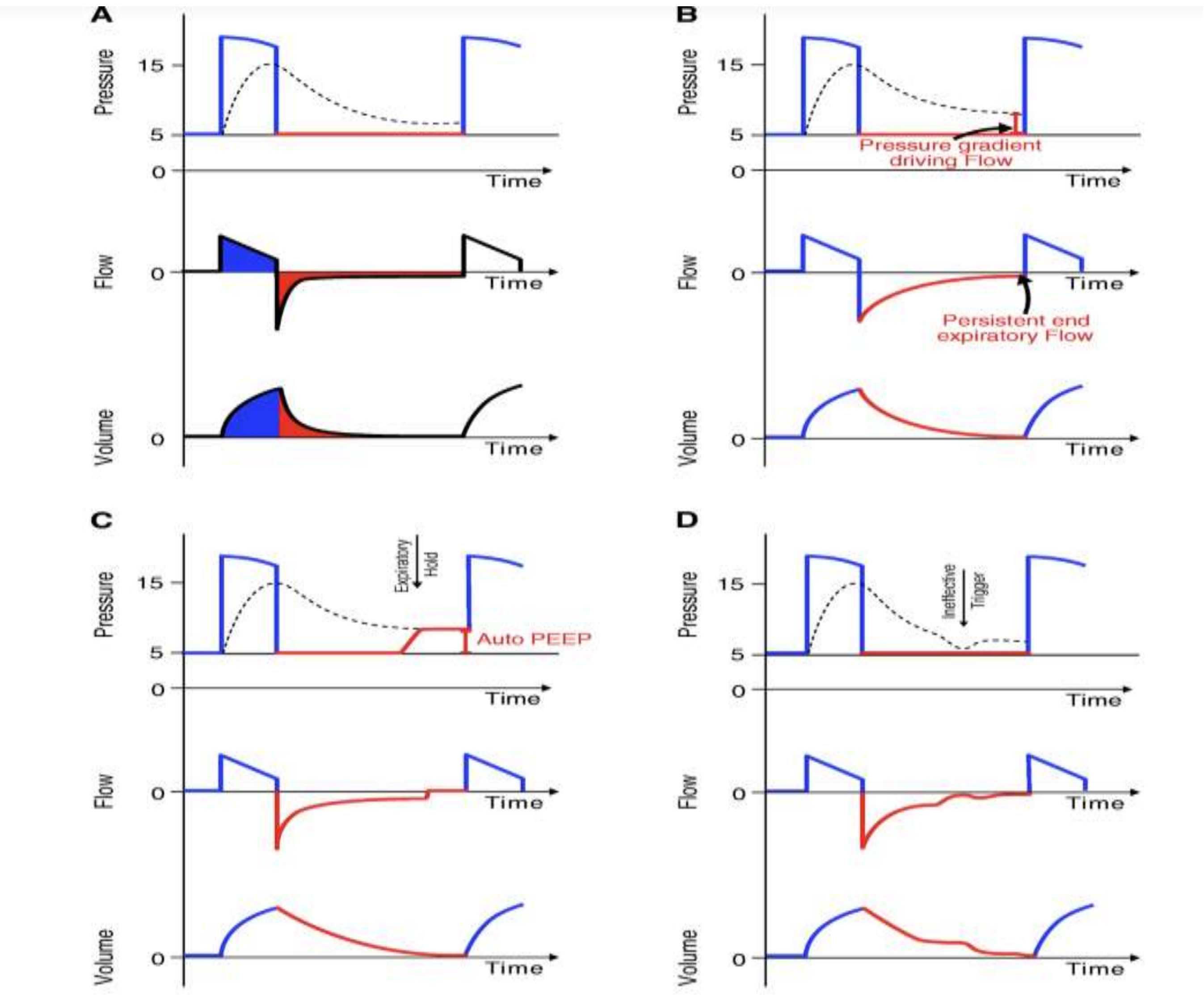
Figure 3.—Flow (upper) and airway pressure (lower) scalars from a patient receiving mechanical ventilation in volume-controlled ventilation. At the beginning of the inspiratory effort (gray arrows), there is still a persistent expiratory flow (autoPEEP). Those cycles also show early attempts to breathe that are not followed by flow delivery, in other words, an ineffective inspiratory effort (IIE; black arrows). IIE are the consequence of trying to breath against a large elastic load (observe airflow at the beginning of the IIE). In the first cycle shown (open arrow), however, a deeper inspiratory effort successfully produces airflow delivery even when expiratory flow at the beginning of the effort is high (suggesting high autoPEEP levels).

- Contraction of inspiratory muscles during expiration leads to inspiratory muscles damage
- Identified in the expiratory part of the flow scalar as dip in flow


MAQUET
PS/CPAP
Admit patient
Nebulizer
Status
Check battery status
22/01 11 40
Ppeak (cmH2O) 19
Pmean (cmH2O) 11
PEEP (cmH2O) 8
RR (b/min) 31
O2 (%) 31
Vee (l/min) 3
Ti/Ttot 0,33
MVi (l/min) 13,0
MVe (l/min) 12,2
VTi (ml) 570
VTe (ml) 389
MVe sp (l/min) 12,2
Additional settings
O2 conc. 31 %
PEEP 8 cmH2O
PS above PEEP 10 cmH2O
Next page
Alarm profile
Save
Trends
Neural access
Quick access
Menu
Main screen

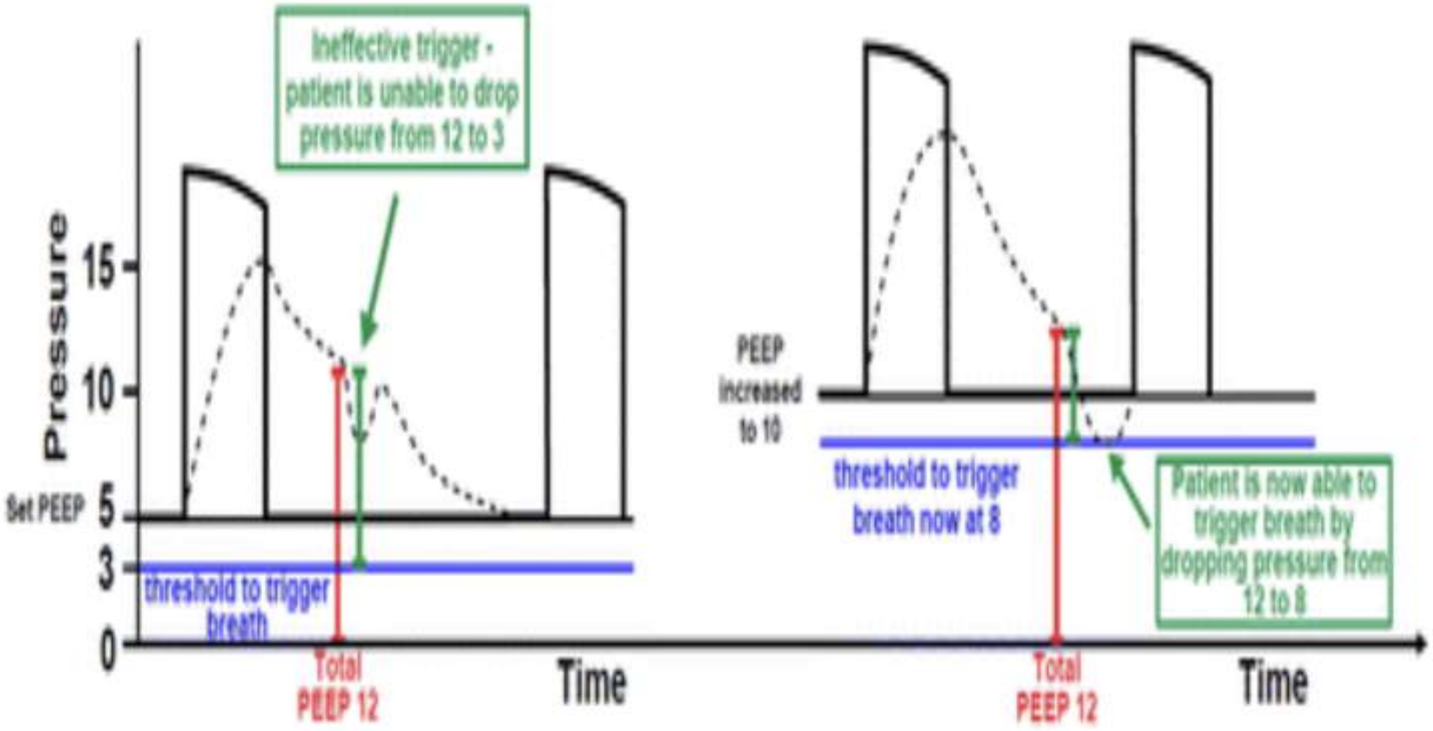
How to detect an auto PEEP?

- Asymmetry of areas under curve
- Persistent end expiratory flow
- End expiratory hold
- Ineffective triggering



Keller M et. Al., How I Teach Auto-PEEP: Applying the Physiology of Expiration. ATS Sch. 2022 Oct 12;3(4):610-624

How auto PEEP causes ineffective trigger?? What is the solution??



- Decreasing the respiratory rate – +/- sedation or paralysis (sos)
- Increasing inspiratory flow rate
- Minimizing resistance(time constant - RCexp) using bronchodilators, corticosteroids and secretions suctioning
- Reducing pressure support to optimal level
- Decreasing tidal volume—> increases RR —> again auto PEEP. NOT TO BE DONE

Trigger sensitivity

- Types of trigger sensitivity :
  - ✓ Pressure
  - ✓ Flow
  - ✓ Volume – not in clinical practice
  - ✓ Time
  - ✓ Neural (NAVA based)
- Higher trigger sensitivity is associated with more auto triggering

- Trigger sensitivity is balanced between too much insensitive settings and too much sensitive setting

Different trigger modes with respect to patient – ventilator interaction

Flow trigger	Pressure trigger	NAVA trigger
Minimum flow to be generated to trigger the ventilator, without much decrease in pressure	Minimum pressure has to be generated to trigger the ventilator. WOB +	Electrical activity of diaphragm – inspiratory trigger
Trigger delay	Trigger delay	No trigger delay
Ineffective during leaks	Ineffective during leaks	Effective during leaks

Shah SD, Anjum F. Neurally Adjusted Ventilatory Assist (NAVA) [Updated 2023 May 22]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2023 Jan-.
Hill LL et al., Flow triggering, pressure triggering, and autotriggering during mechanical ventilation. Crit Care Med. 2000 Feb;28(2):579-81.

Flow versus pressure triggering in patient-ventilator interaction

- Flow triggering improved oxygenation (higher Pmean), dynamic compliance compared to pressure triggering in 32 patients mechanically ventilated
- In another study of 100 patients, flow triggering improved oxygenation index, duration of weaning and ventilation when compared to pressure triggering
- Inspiratory muscle effort, therefore the work of breathing was lower with flow triggering compared with pressure triggering

Al-Najjar, M.A. et al. The effect of triggering type on post-triggering pressure variations during pressure support ventilation: a simplified surrogate for dyssynchrony. Egypt J Bronchol **12**, 41–48 (2018).
Khalil, M.M., Elfattah, N.M., El-Shafey, M.M. *et al.* Flow versus pressure triggering in mechanically ventilated acute respiratory failure patients. *Egypt J Bronchol* **9**, 198–210 (2015).
Aslanian P et al,. Effects of flow triggering on breathing effort during partial ventilatory support. Am J Respir Crit Care Med. 1998 Jan;157(1):135-43.

Double triggering

- Two mechanical breaths “stacked,” one after the other, without expiration between them or an expiratory time less than half of the mean inspiratory time
- Causes:

✓ High ventilatory demand

✓ Short inspiratory time

✓ Insufficient level of pressure support

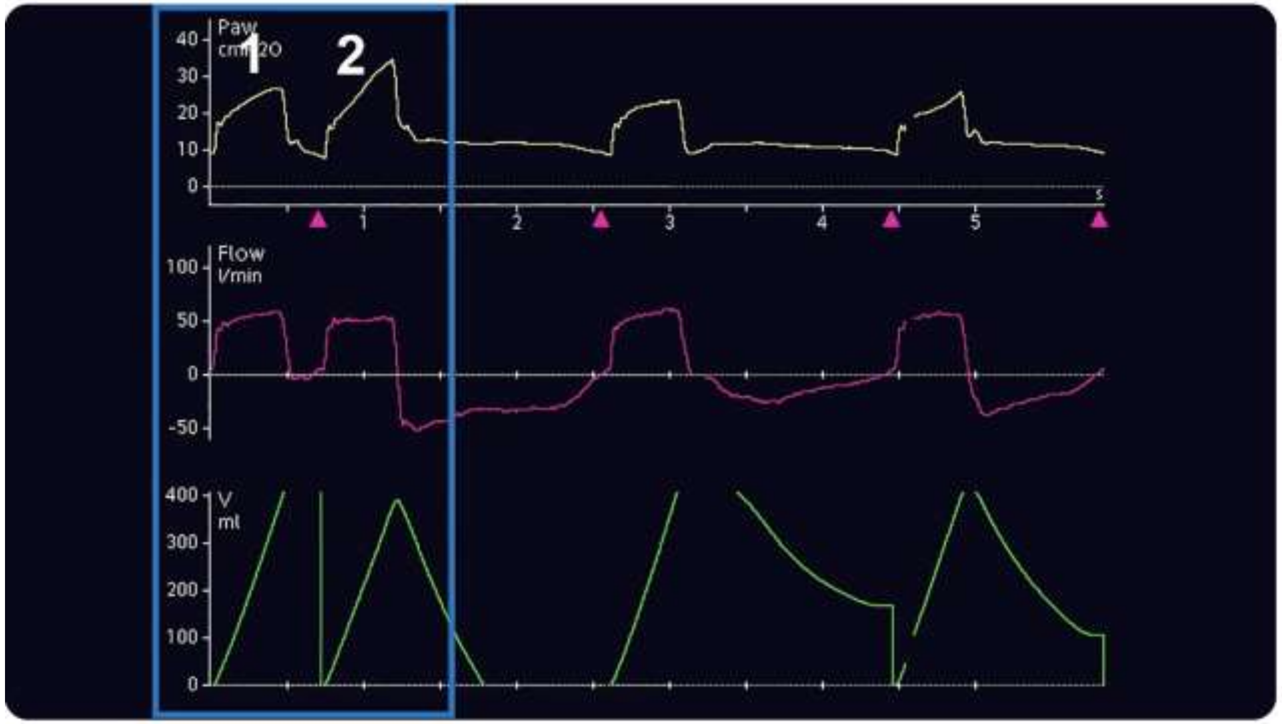
✓ Inadequate inspiratory volume

Lian, Jin Xiong BSN, RN, CNS. Using ventilator waveforms to identify and eliminate double triggering. Nursing Critical Care 6(6):p 18-23, November 2011
James M. Bailey; Management of Patient–Ventilator Asynchrony. Anesthesiology 2021; 134:629–636

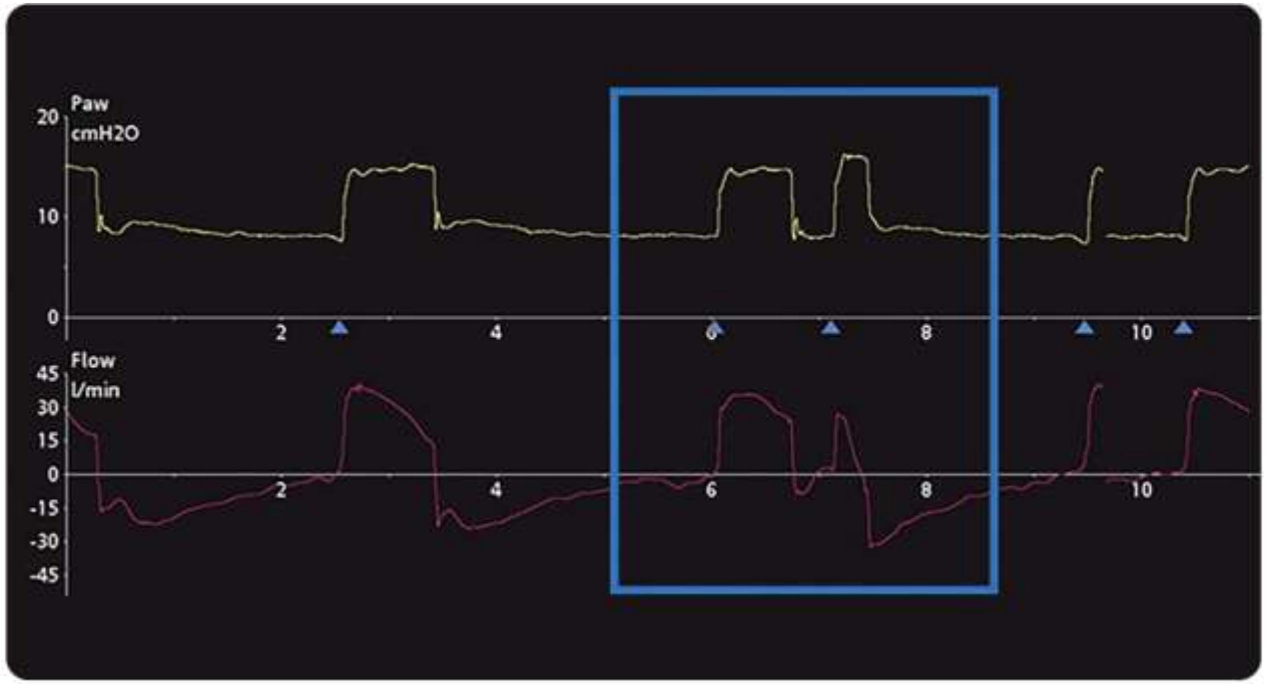
Types of double triggering

- DT – A (auto-triggering)
- DT – V (Reverse triggering)
- DT– P
- Patient triggered breaths can be identified by the drop in the oesophageal pressure (patient's neural inspiration)
- Pressure decrease of > 0.49 cm H_2O in trigger delay phase can distinguish DT-P breath from DT-A and DT-V breaths

Liao KM, Ou CY, Chen CW. Classifying different types of double triggering based on airway pressure and flow deflection in mechanically ventilated patients. Respir Care. 2011 Apr;56(4):460-6.

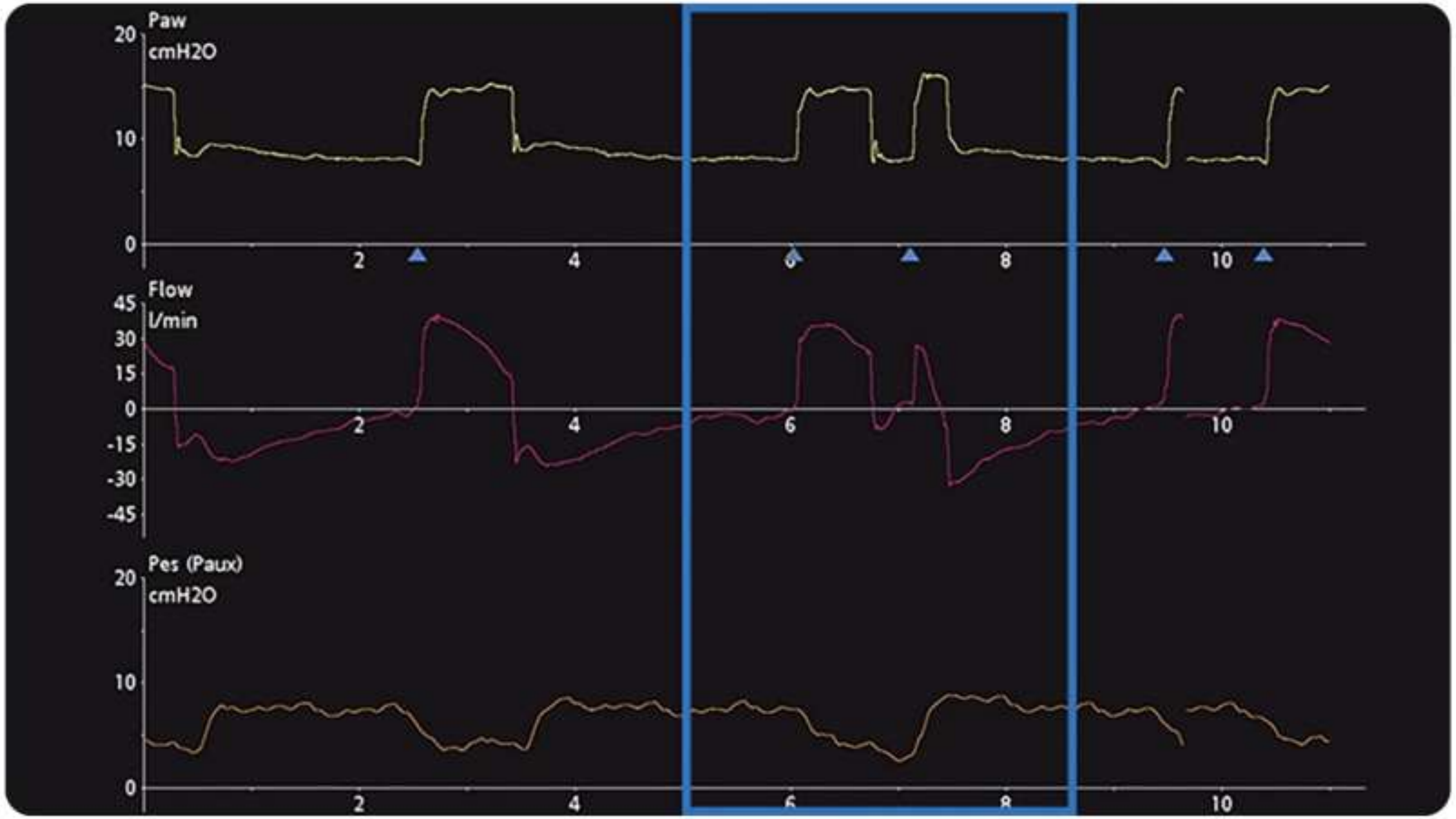


Paw
cmH2O
1
2
Flow
l/min
V
ml



Paw
cmH2O
Flow
l/min

DT - P


Paw
cmH2O
20
10
0
2
4
6
8
10
Flow
l/min
45
30
15
0
-15
-30
-45
2
4
6
8
10
Pes (Paux)
cmH2O
20
10
0
2
4
6
8
10

Auto triggering (DT – A)

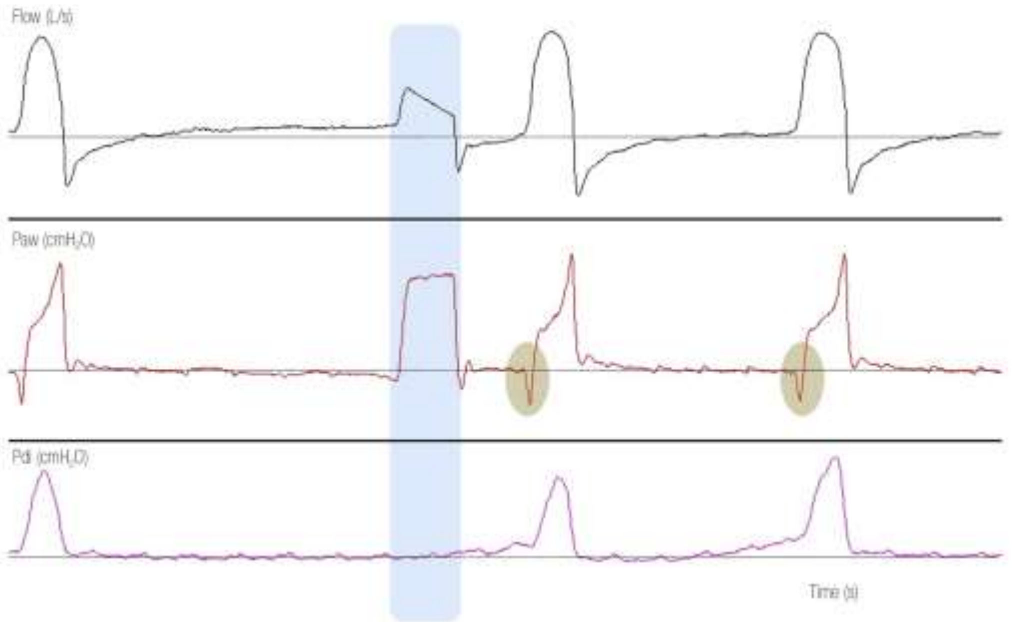


Figure 4. Airway pressure (Paw), flow and transdiaphragmatic pressure (Pdi) time curves of a patient ventilated on pressure support ventilation are illustrated. As indicated by the absence of Pdi increase, there is no inspiratory effort before the second mechanical breath (autotriggered breath, see blue shaded area). We can observe that, in comparison to patient-triggered breaths, where a decrease in Paw is observed before the start of mechanical inflation (grey shaded areas), there is no distortion in the Paw- (no decrease in Paw) and flow-time curve in the autotriggered breath. Moreover, the shape of the inspiratory flow-time curve is different compared to that of patient-triggered breaths. Notice the absence of dynamic hyperinflation in this patient (expiratory flow returns to zero after each breath).

- Delivery of ventilator breath without patient effort
- Causes: artefact (cardiac oscillation, secretions, water in the tube), low trigger sensitivity, circuit leaks

Reverse triggering (DT – V)

- Mechanical insufflation of the respiratory system spontaneously trigger the breath without being initiated by patient himself (heavy sedated patients)
- Exact mechanism not understood
- In reverse triggering, flow delivered by the ventilator is thought to activate stretch receptors in the upper airways, lung, and chest wall that provide afferent feedback to the respiratory center, which then matches the frequency of the external stimulus
- Common with volume control mode of ventilation

Murray B et al., Reverse Triggering: An Introduction to Diagnosis, Management, and Pharmacologic Implications. Front Pharmacol. 2022 Jun 22;13:879011

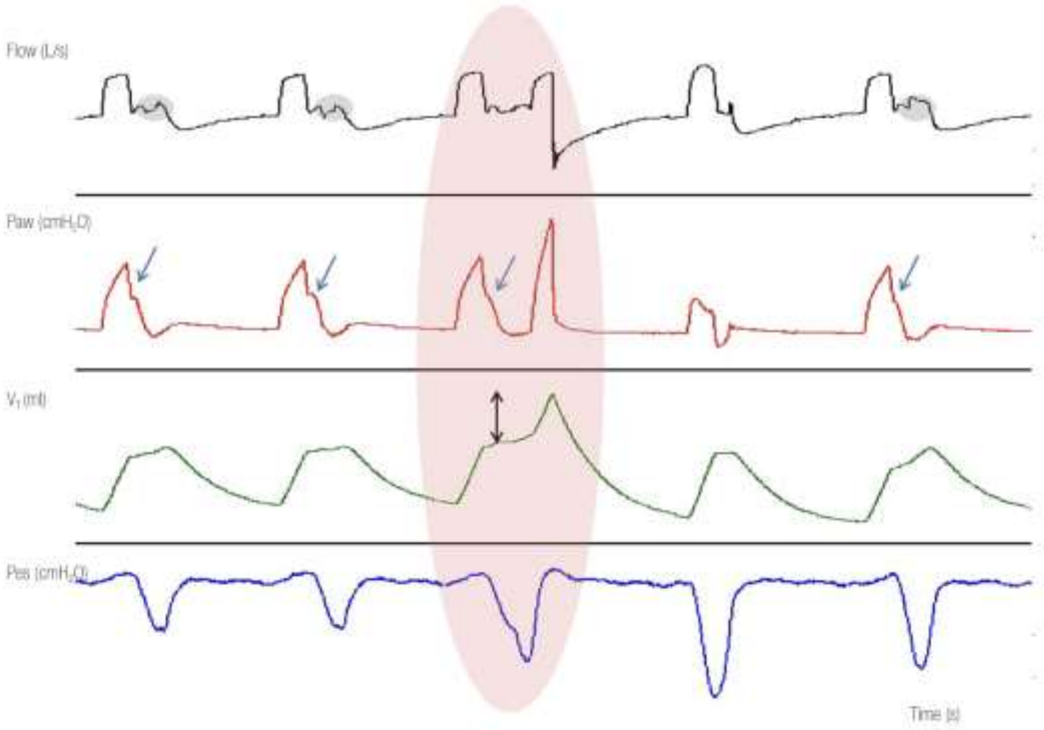


Figure 7. Reverse triggering in a patient ventilated with assist volume control ventilation. Esophageal pressure (Pes) decrease reveals patient inspiratory efforts (blue line) after every mechanical inflation in 1:1 relationship. Indirect evidence of patient inspiratory activity during mechanical inflation is the flow distortion (grey shaded area) and the disappearance (blue arrows) of plateau airway pressure (Paw) in the flow-time and Paw-time waveform, respectively. In this patient, a reverse triggered breath was strong enough to trigger the ventilator at the end of the mechanical inspiration, causing breath stacking (red shaded area). Inflated tidal volume (V_T) during breath stacking increased from 444 ml to 800 ml (double arrow).

Management of reverse triggering

- Ventilator management:
  - ➢ Consider changing to support mode of ventilation when it is safe
  - ➢ Adjust ventilator rate
  - ➢ Effect of tidal volume and PEEP adjustment in reverse triggering mx has conflicting results
- Pharmacological management: (when ventilator adjustment is not possible or failed)
  - ➢ Sedation
  - ➢ Neuromusclular blocking agents

Flow dys-synchrony due to insufficient flow (air hunger)

- Insufficient flow of gas to the patient leads to unsatisfied patient ventilatory demand
- Common with volume controlled mode with fixed flow
- Characterised by concavity in the pressure-time scalar in the inspiratory part
- When severe, lead to double trigger
- Causes:
  - ➢ Patient related factors - pain, anxiety, fever, metabolic acidosis
  - ➢ Ventilator factors: low tidal volume, high inspiratory time, high rise time

Saavedra SN, Barisich PVS, Maldonado JBP, Lumini RB, Gómez-González A, Gallardo A. Asynchronies during invasive mechanical ventilation: narrative review and update. Acute Crit Care. 2022 Nov;37(4):491-501

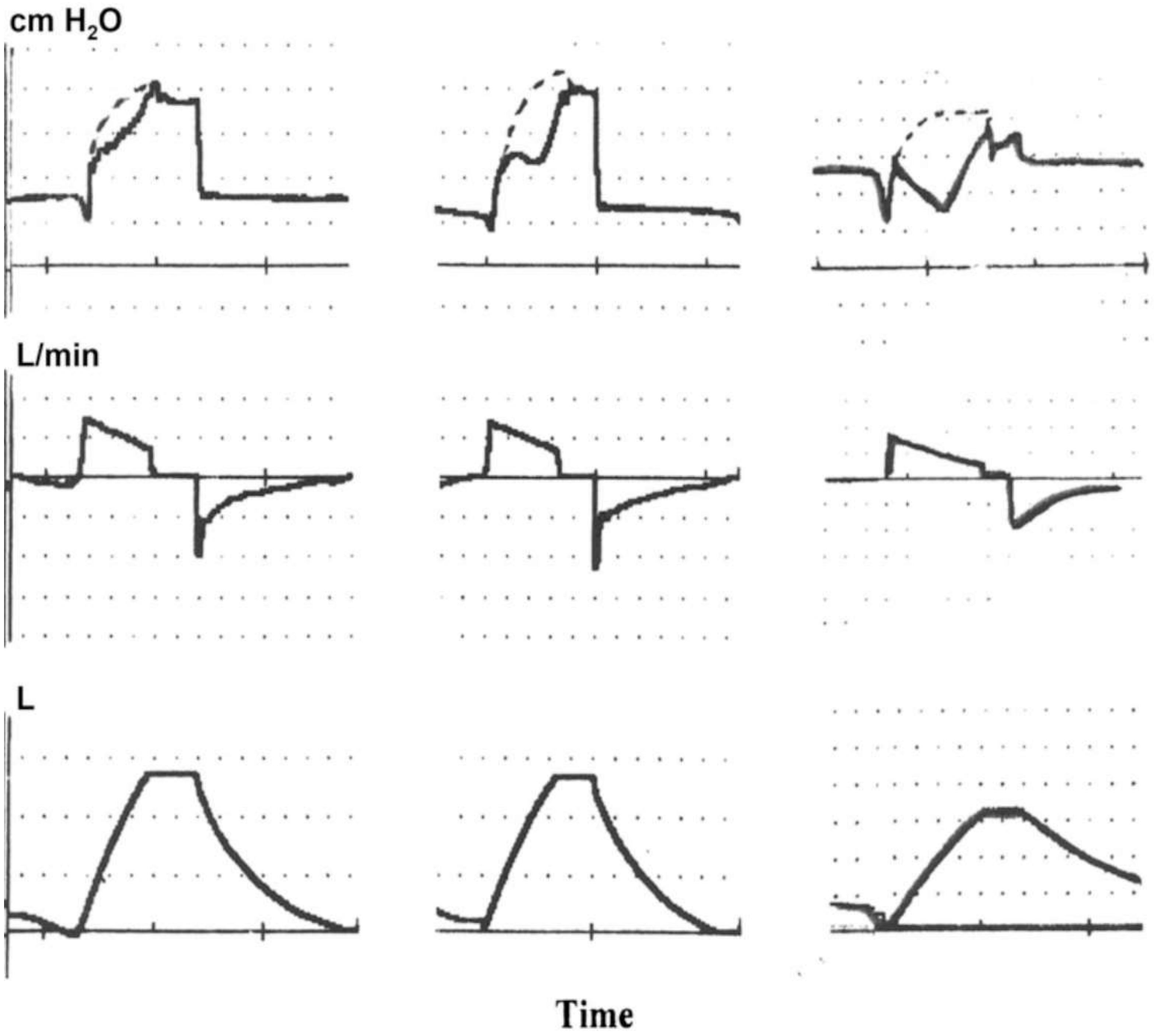
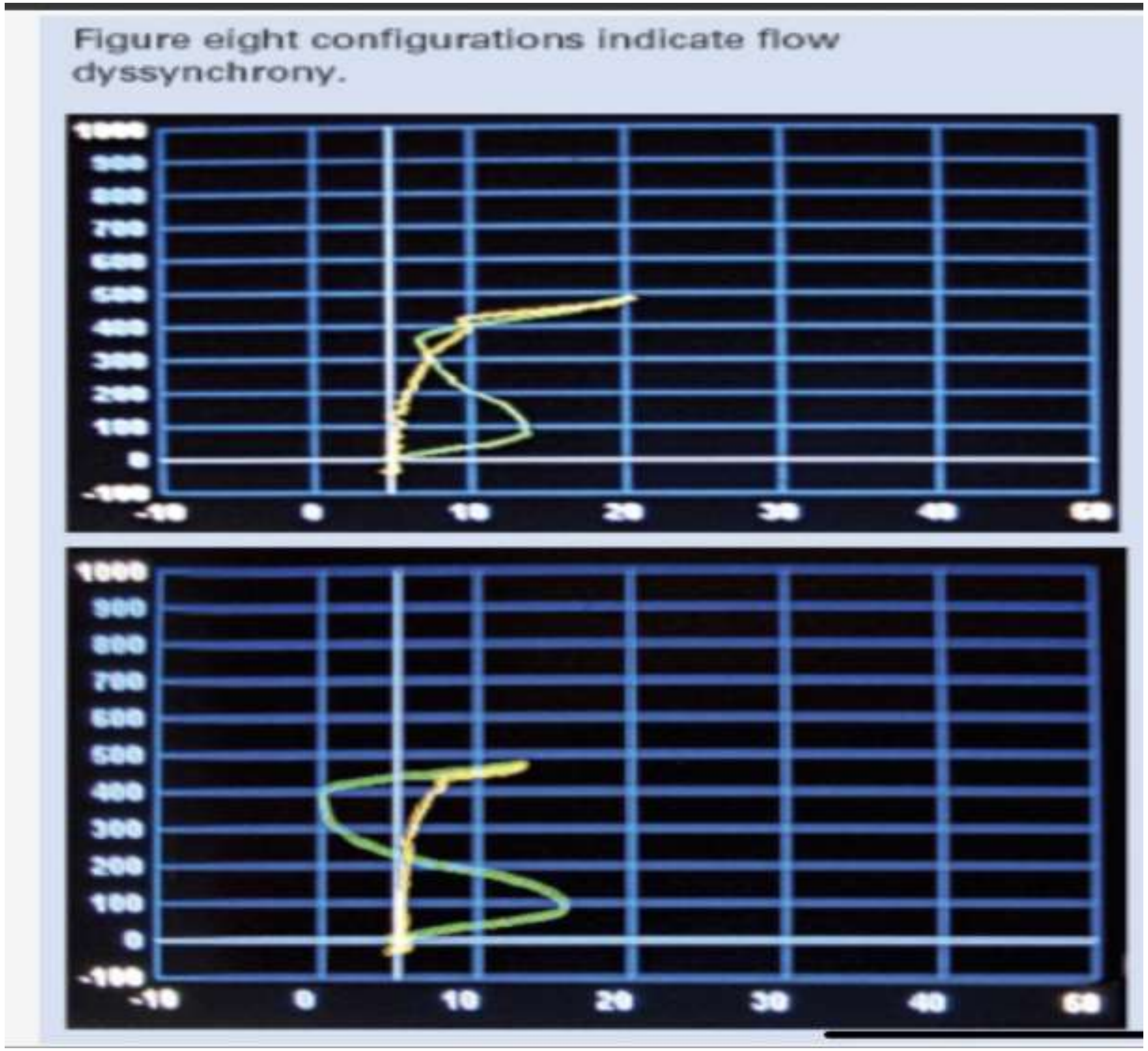


Figure 3. Plotted are airway pressure, flow, and volume over time during three assisted breaths. The *dotted airway pressure line* represents that observed during a control breath with a similar tidal volume as the assisted breath. *Left*: The assisted breath airway pressure profile remains smoothly positive and tracks with the control breath airway pressure profile, suggesting that the inspiratory muscle loading is likely not excessive. *Middle*: The assisted breath airway pressure profile is uneven and appears to be markedly "sucked down" by patient effort during much of the breath. This might suggest that the flow delivery is inadequate for patient demand to the point that inspiratory muscle overload may be present. *Right*: The assisted breath airway pressure profile goes below the baseline (expiratory) pressure. Flow is thus inadequate to provide any inspiratory muscle unloading.



Lian, J. X. (2010). Using ventilator waveforms to optimize patient-ventilator interaction. Nursing Critical Care, 5 (5), 14-24.


MAQUET
Nebulizer
Check battery status
Paw high
01-23 09:45
Ppeak
28
13
8
20
28
4
1.10
1:1.9
7.8
8.0
395
394
28
8
20
350

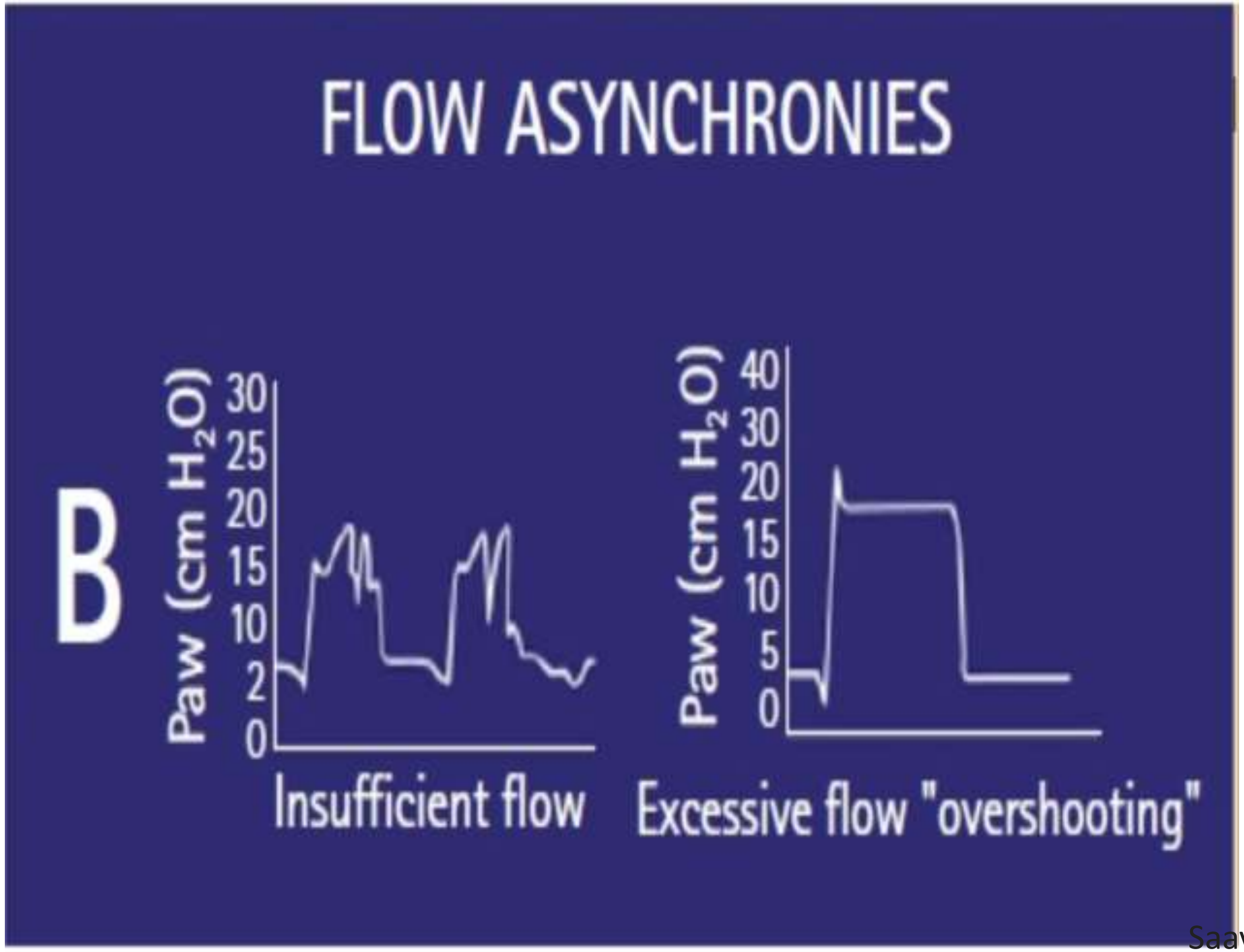

Patient
Additions
Modes
16 Ppeak cmH2O
4.6
355
15
1:4.6
20
7
79.1
1.58
1.14
IntelliCuff
Psupport
PEEP/CPAP
Oxygen
Oxygenation
CO2 elimination
00:20
35
5
4.6
10
42
100
Controls
Alarms
Monitoring
Graphics
Tools
Events
System

Solutions

- In flow targeted modes - shape of flow adjustment (sinusoidal/square/decelerating), usage of inspiratory pause time
- Consider changing to pressure targeted mode - flow varies with patient effort, rate of inspiratory pressure rise adjustment
- Control of pain, anxiety, fever and metabolic disturbances

Gilstrap D, MacIntyre N. Patient-ventilator interactions. Implications for clinical management. Am J Respir Crit Care Med. 2013 Nov 1;188(9):1058-68

Excessive flow – pressure overshoot



- Peak in the inspiratory part of the pressure curve
- Solutions:
  - ➢ Decrease the flow
  - ➢ Decrease the inspiratory pressure support

Saavedra SN, Barisich PVS, Maldonado JBP, Lumini RB, Gómez-González A, Gallardo A. Asynchronies during invasive mechanical ventilation: narrative review and update. Acute Crit Care. 2022 Nov;37(4):491-501


MAQUET
Volume Control
Admit patient
Nebulizer
Check battery status
Paw high
01-27 22:27
28
29
15
7
26
32
7
0.82
1:2.0
9.4
9.8
465
538
32
7
20
360

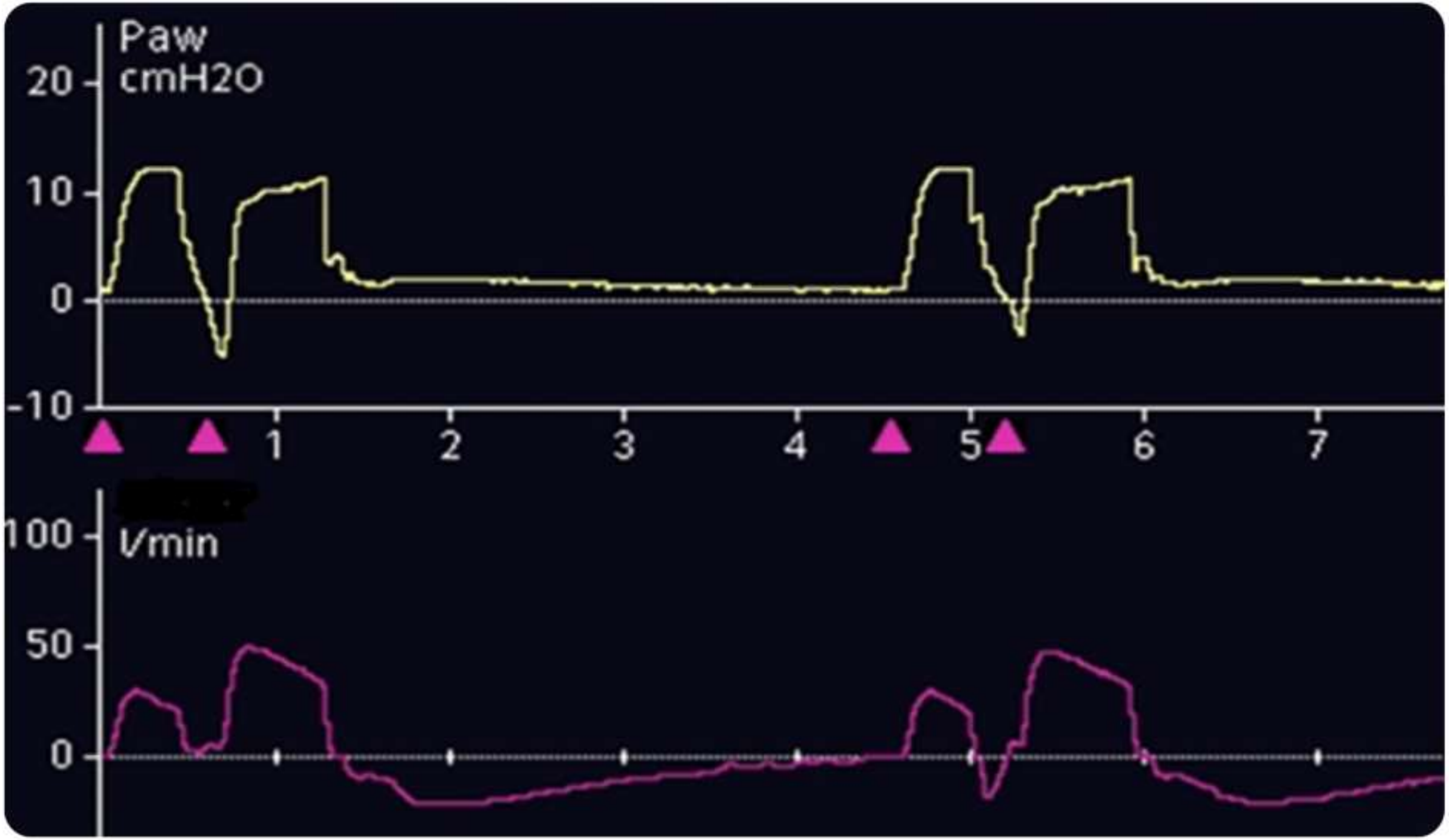
Cycling dys-synchrony

- Mismatch between patient inspiratory time and ventilatory inspiratory time
- Types:
  - ➢ Premature cycling
  - ➢ Delayed cycling

Premature cycling

- Set mechanical inspiratory time is less than the neural inspiratory time
- The inspiratory muscles continue to contract and when severe initiate a second breath resulting in double triggering
- Higher flow cycling results in premature cycling
- Premature cycling results in breath stacking, more inspiratory effort, higher respiratory rate and resultant lung injury

Gentile MA. Cycling of the mechanical ventilator breath. Respir Care. 2011 Jan;56(1):52-60


Paw
cmH2O
20
10
0
-10
1
2
3
4
5
6
7
[redacted]
100
l/min
50
0

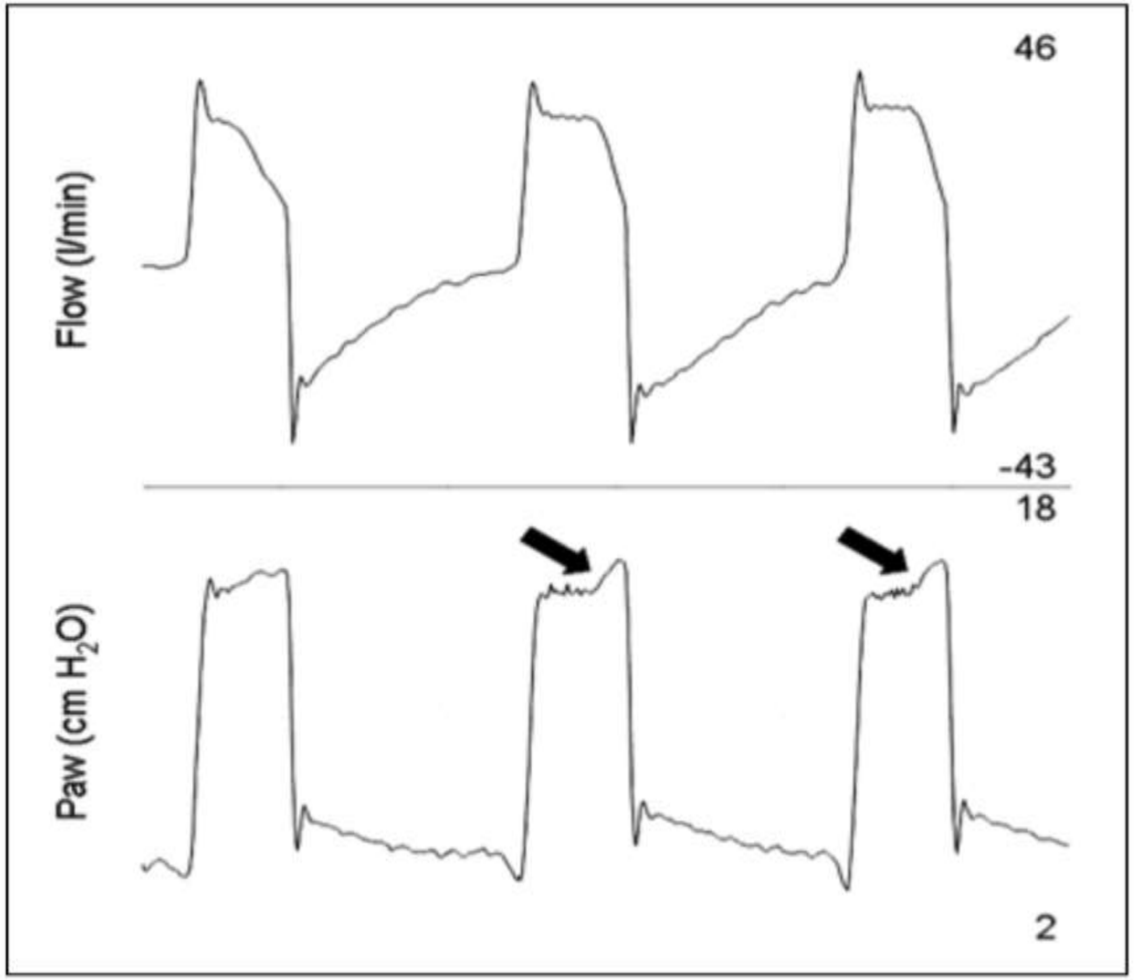
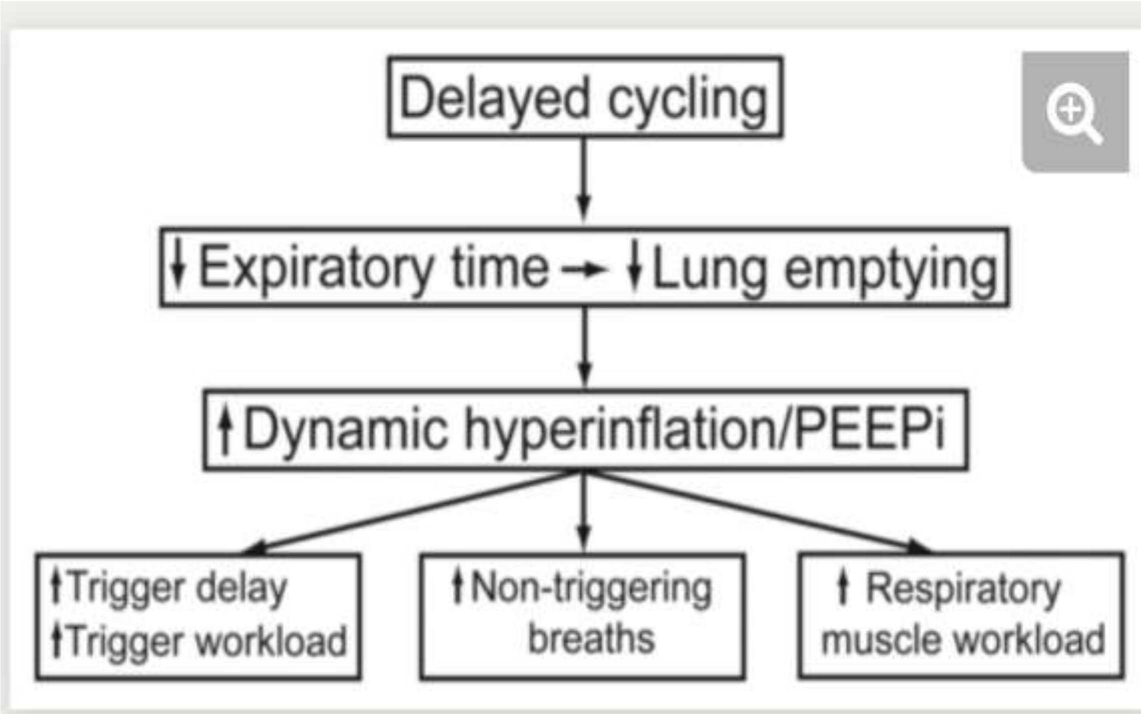


Figure 4.—The lower trace shows airway pressure in a patient receiving ventilatory support in pressure support ventilation. There is a sudden increase in airway pressure (arrows) at the end of inspiration (even when airflow is decreasing, upper trace), produced by the activation of patient's expiratory muscles.

- Delayed cycling – patient inspiratory time is lesser than the ventilator inspiratory time
- Common in COPD
- Prolonged inspiratory time leads to dynamic hyperinflation and resulting consequences



Murias G, Villagra A, Blanch L. Patient-ventilator dyssynchrony during assisted invasive mechanical ventilation. Minerva Anestesiol. 2013 Apr;79(4):434-44
Gentile MA. Cycling of the mechanical ventilator breath. Respir Care. 2011 Jan;56(1):52-60

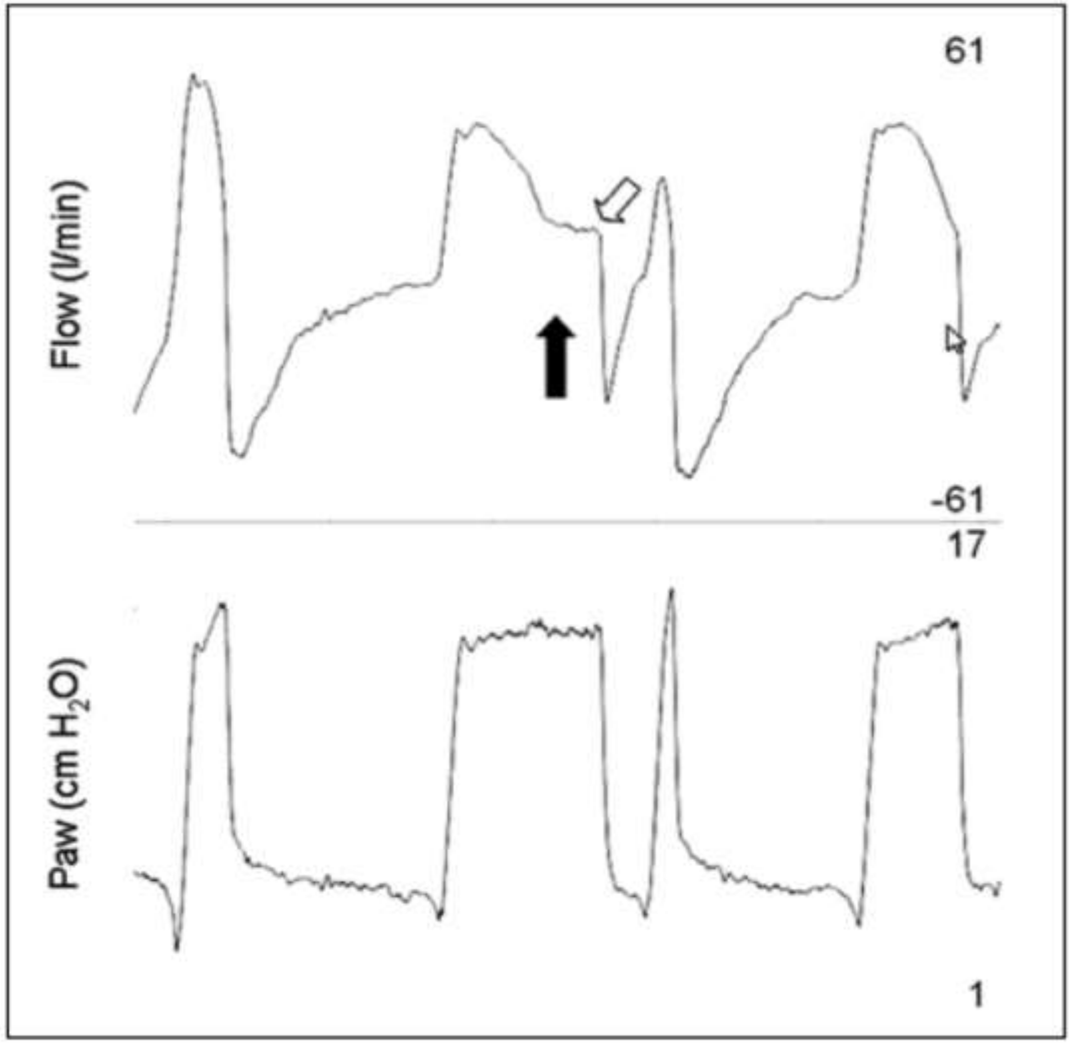


Figure 5.—During pressure support ventilation, a gas leak (a bias flow, open arrow) can prevent airway flow from reaching the cycling-off threshold (black arrow). In this scenario, an added time criterion ends inspiration.

- Cycling dys-synchrony in the presence of gas leaks
- Modern ventilators has time cycling as a back up to end the inspiratory cycle when there are leaks in the ventilator


18
Pmean (cmH2O) 10
PEEP (cmH2O) 5
RR (b/min) 26
O2 (%) 42
I:E 1:1.3
MVe (l/min) 9.4
VTi (ml) 395
VTe (ml) 373
80 l/min BTPS
700 ml BTPS
Additional settings
O2 conc. 44 %
PEEP 6 cmH2O
Resp. Rate 20 b/min
PC above PEEP 10 cmH2O
Additional values

2023-12-10 22:24:06
INTELLiVENT
Patient
Additions
Modes
NIV
13 Ppeak cmH2O
9.0 MinVol NIV l/min
518 VTE NIV ml
26 fTotal b/min
1:2.6 I:E
7 Rinsp
5 Rexp
98.0 Cstat
0.72 RCinsp
0.84 RCexp
IntelliCuff
8 cmH2O Psupport
4 cmH2O PEEP/CPAP
21 % Oxygen
Controls
Oxygenation
CO2 elimination
Spont/Activity
00:16

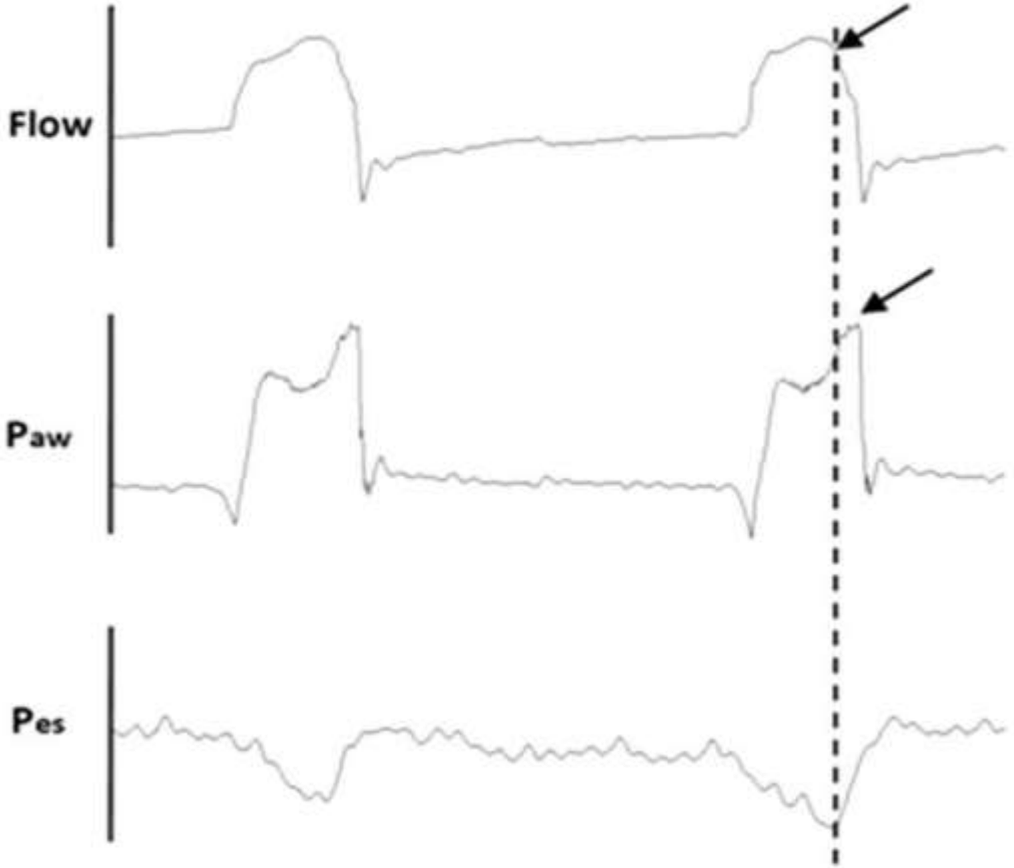
Management of ventilator patient dys-synchrony

- Ventilator adjustments
- Sedation

Oesophageal waveform monitoring w.r.t. PV dys-synchrony

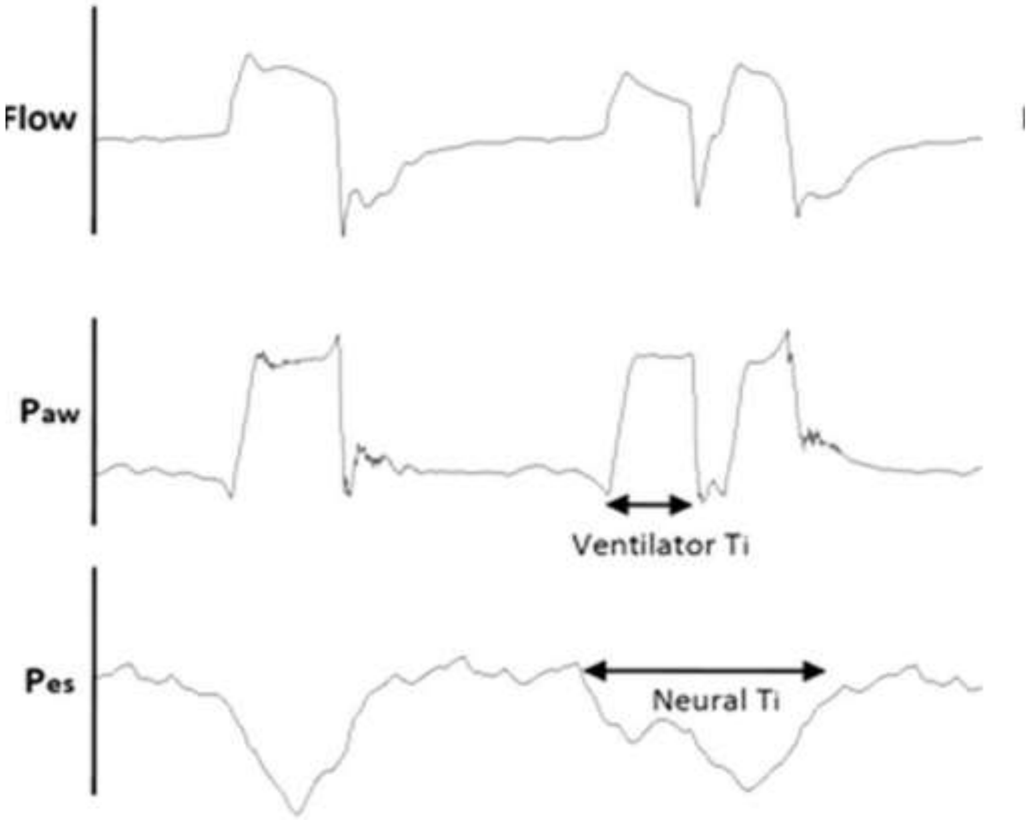
- Inspiratory muscle effort produces change in oesophageal pressure
- Double balloon oesophageal catheter can measure both Pga and Poes. The difference between them gives the Pdi
- Normal values: Delta Poes = 3 -12 cm H20; Delta Pdi = 5-15 cm H20

Annemijn H. Jonkman et al.,European Respiratory Review 2023 32: 220186;

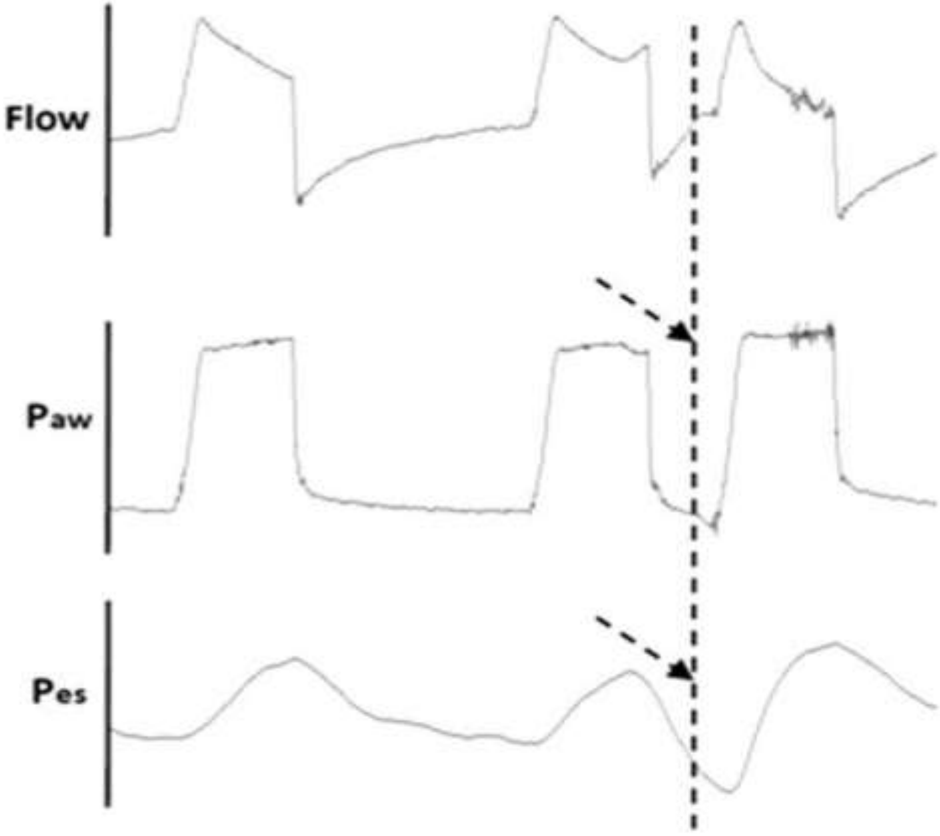


a Delayed cycling

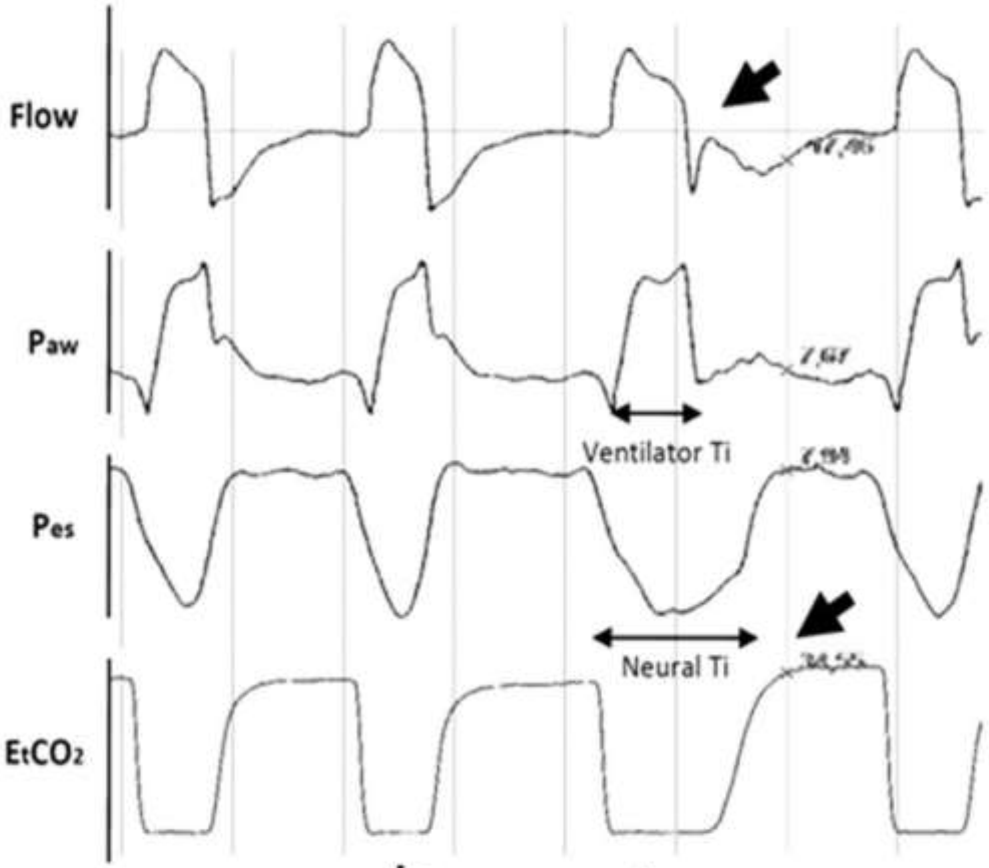
Mauri T et al.,PLeUral pressure working Group (PLUG—Acute Respiratory Failure section of the European Society of Intensive Care Medicine). Esophageal and transpulmonary pressure in the clinical setting: meaning, usefulness and perspectives. Intensive Care Med. 2016 Sep;42(9):1360-73.



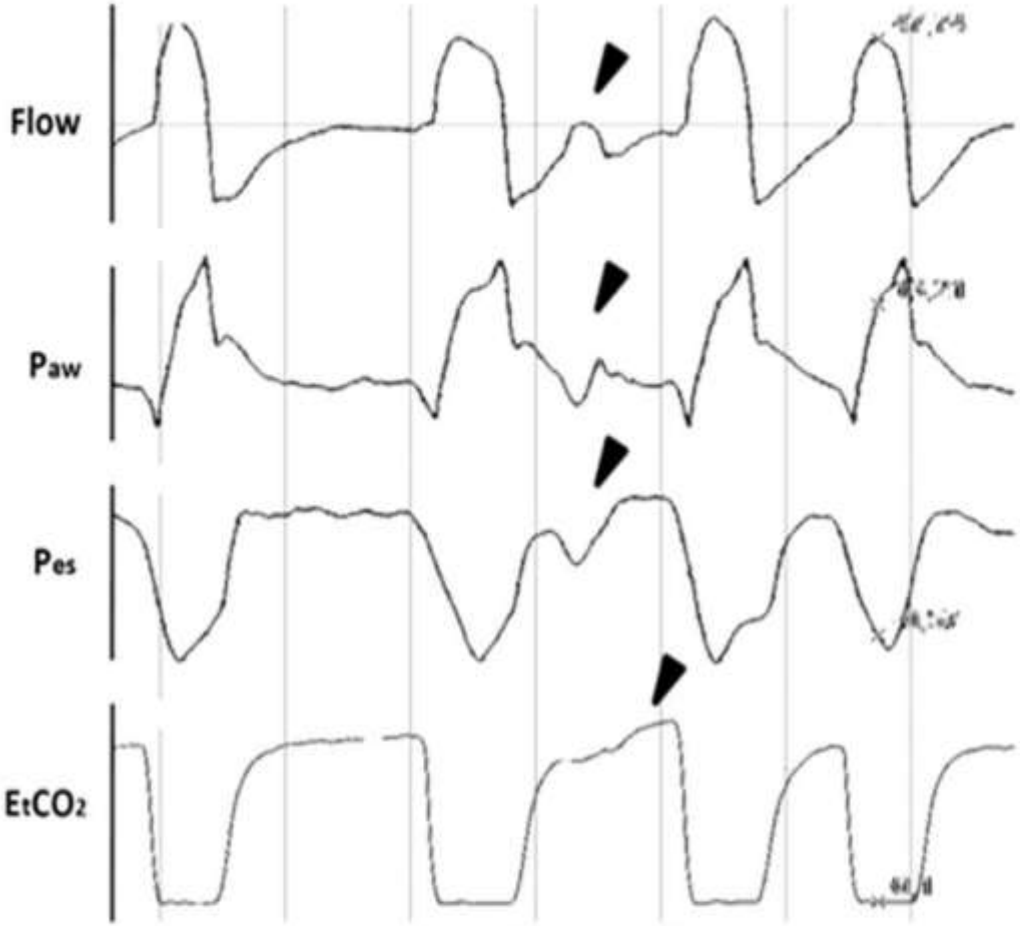
b Double triggering (with breath stacking)



C Reverse triggering (with breath stacking)

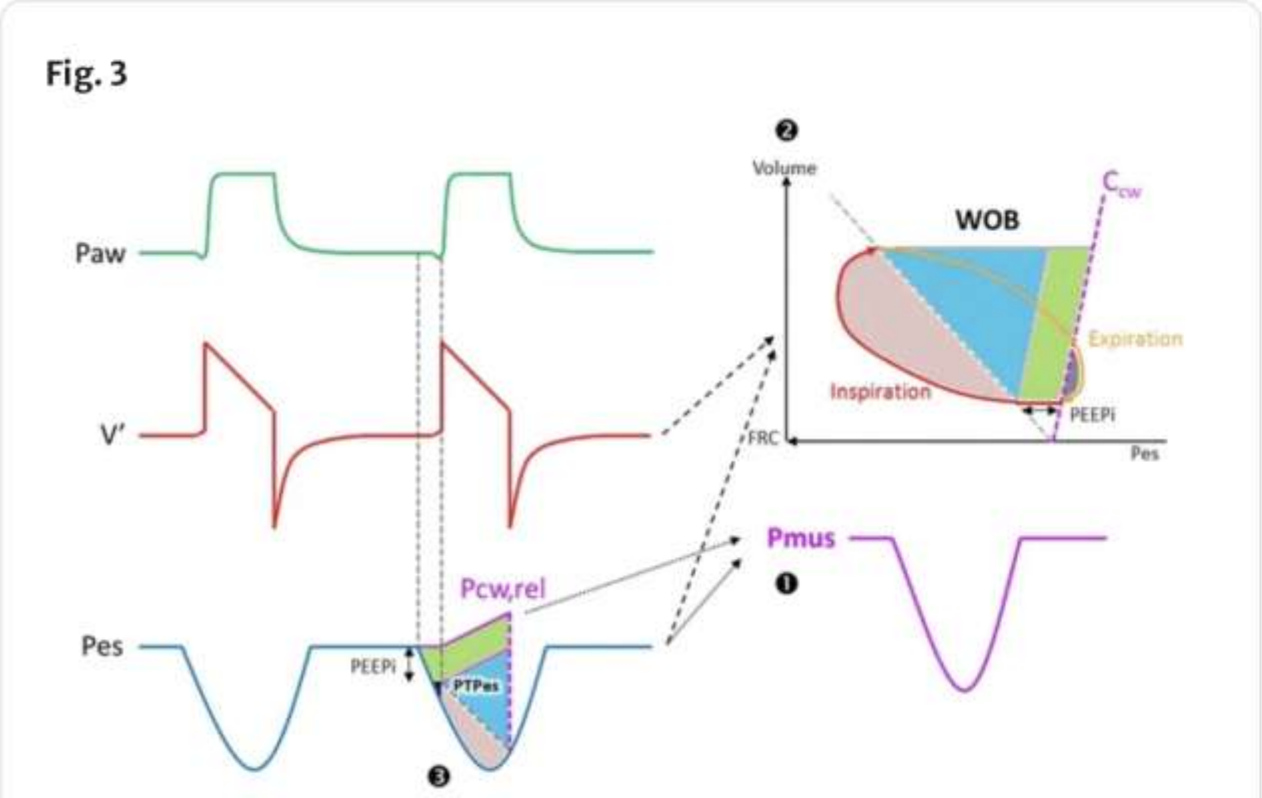


d Premature cycling



e Ineffective effort

Quantification of inspiratory muscle effort w.r.t. PV dys-synchrony



- Pcw - elastance by the chest wall during expiration(static recoil)
- Pmus - inspiratory muscular pressure
- V- volume
- WOB - volume displaced * Pmus joules/ litres or joules/min (normal - 0.35 to 2.4) - not useful in isometric effort
- Pmus. - denote pressure required to overcome elastic recoil forces of the chest wall, iPEEP and inspiratory effort
- PTPes - Pmus * t (correlated with inspiratory muscle effort ie) energy and oxygen consumption of inspiratory muscles) (Normal - 50 to 150 cm H20/min)
- Pmus = Pcw - Poes
- Application: Diaphragm protective ventilation

Mauri T et al.,Esophageal and transpulmonary pressure in the clinical setting: meaning, usefulness and perspectives. Intensive Care Med. 2016 Sep;42(9):1360-73.

Diaphragm protective ventilation

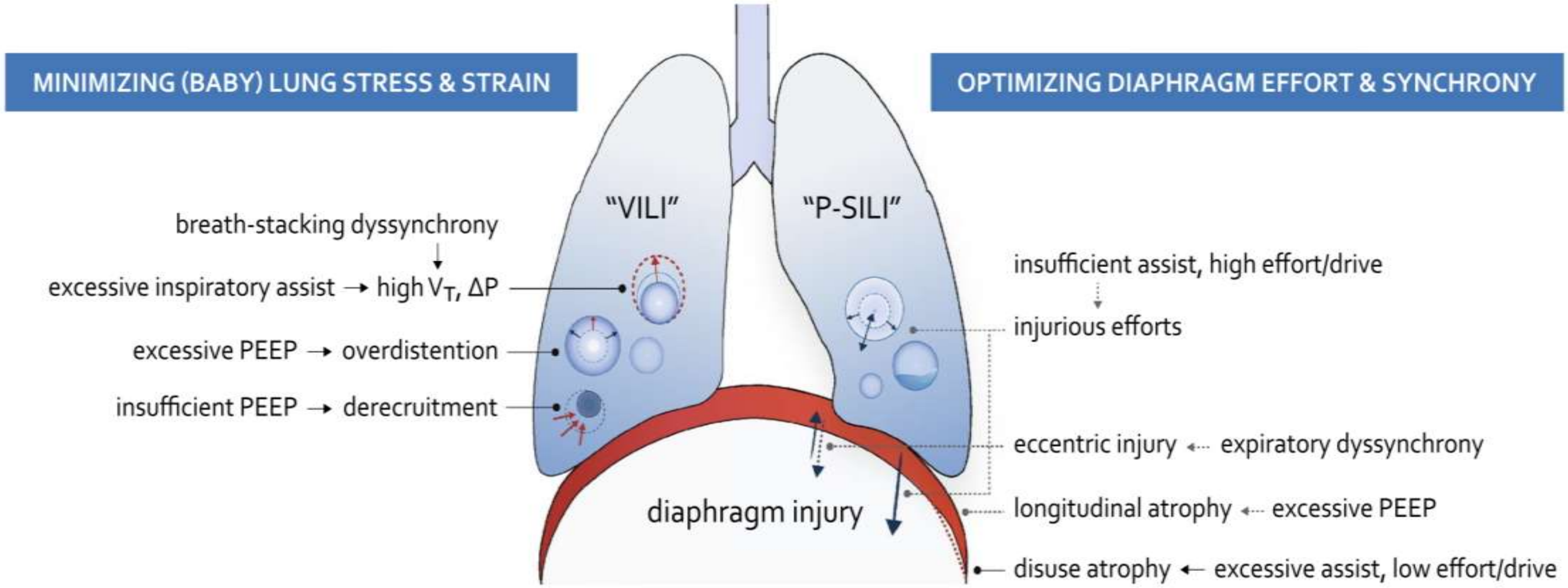


Fig. 1 Principles of lung and diaphragm-protective ventilation. ΔP: change in airway pressure during inspiration; PEEP: positive end-expiratory pressure; P-SILI: patient self-inflicted lung injury; VILI: ventilator-induced lung injury; V_T: tidal volume

Electrical diaphragmatic activity w.r.t. PV dys-synchrony

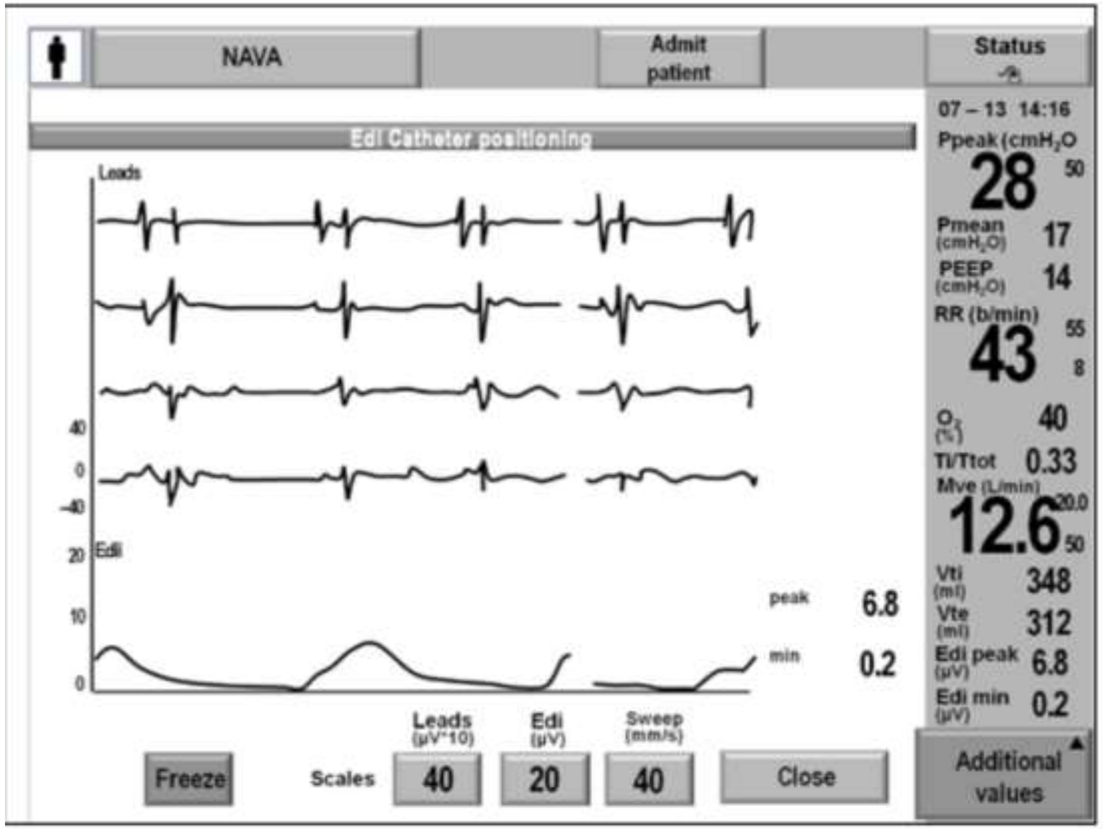


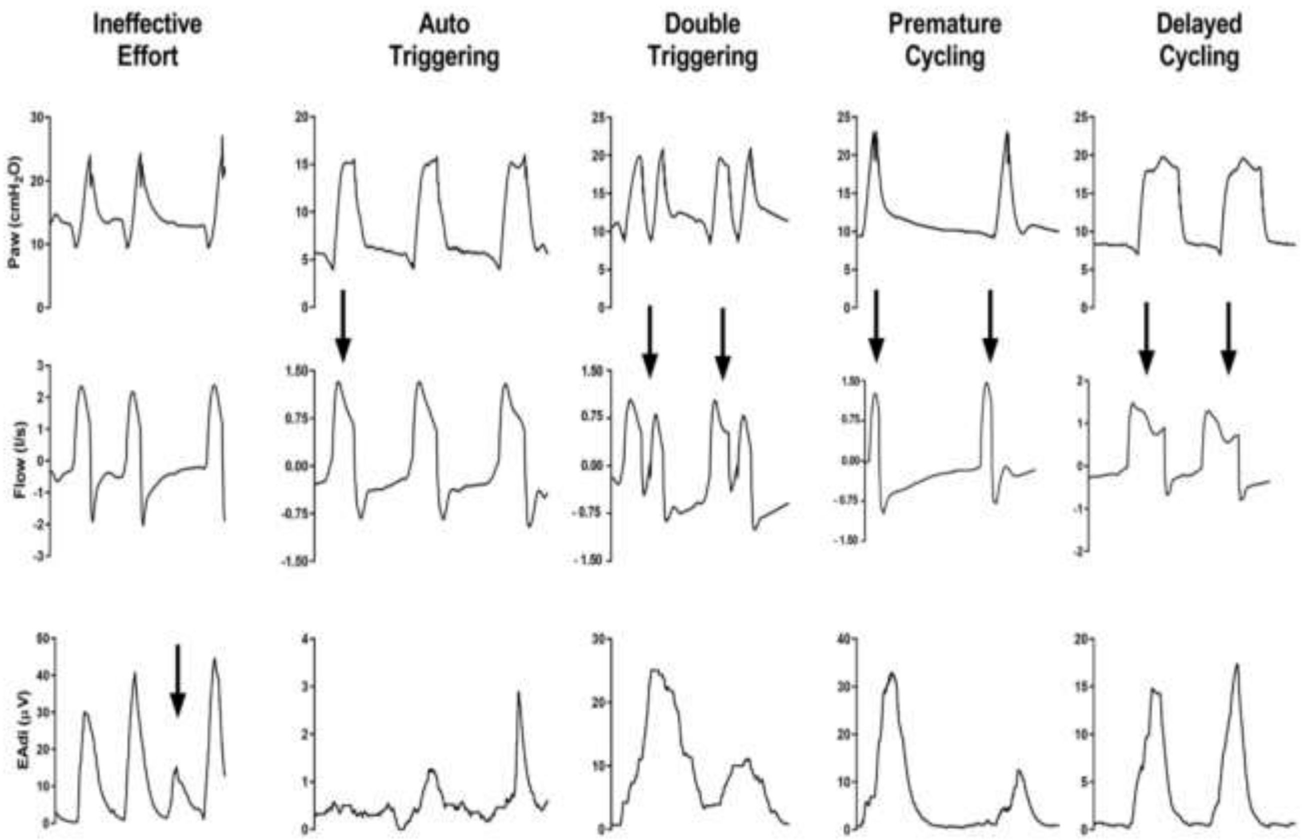
Figure 2: The catheter positioning screen on the SERVOi ventilator (see text for description).

Figure 3: A drawing of the main screen of the SERVOi ventilator. This represents an adult patient in pressure support/CPAP mode. The top waveform is the pressure/time waveform (solid) and the Edi waveform (dashed line). The second waveform is flow/time, the third is volume/time and the fourth (bottom) is Edi/time. Note that the Edi signal from the diaphragm and the pressure waveform from the ventilator do not correspond. This is an example of patient-ventilator asynchrony (See text for further description).

Catheter positioning screen

Trigger delay and cycle dys-synchrony

Pilbeam SP. Monitoring electrical activity of the diaphragm and the ventilation mode NAVA (Neurally Adjusted Ventilatory Assist). Ind J Resp Care 2012; 1(2):112-123



- Uses neural inspiratory output to initiate inspiratory effort and cycling
- Compared to other conventional modes, trigger and cycle dys-synchronies are better

Longhini F et al.,Monitoring the patient-ventilator asynchrony during non-invasive ventilation. Front Med (Lausanne). 2023 Jan 19;9:1119924.

Automatic software detection of PV dys-synchrony – Algorithms - DATA

- Sensitivity and specificity of RT detection automatic algorithm was found to be 83.1% and 99.3% with PPV 97.6% in a analysis of 4509 breath tracing obtained from recording of 20 patients of AHRF(ARDS) ventilated with different modes (1073 – 24%)
- A neural network model (U-net architecture) cross validated with both clinical breath data sets of 15 patients and simulated breaths based on timing was found to have a detection rate of asynchrony (Delayed trigger, premature and delayed cycling, ineffective efforts) with 90% accuracy
- In a study validating 4 different machine learning algorithms to detect ventilator dys-synchrony in 30 patients, 10,000 breaths (normal breaths, double triggered[DT-P & DT-A], reverse triggered[early RT and late RT] and flow limited[Mild or severe] breaths families) with > 80% sensitivity

Pham T et al., Automated detection and quantification of reverse triggering effort under mechanical ventilation. Crit Care. 2021 Feb 15;25(1):60.
Bakkes T et al.,Automated detection and classification of patient-ventilator asynchrony by means of machine learning and simulated data. Comput Methods Programs Biomed. 2023 Mar;230:107333.
Sottile PD et al.,The Development, Optimization, and Validation of Four Different Machine Learning Algorithms to Identify Ventilator Dyssynchrony. medRxiv [Preprint]. 2023 Nov 29:2023.11.28.23299134.

Dys-synchrony according to respiratory mechanics

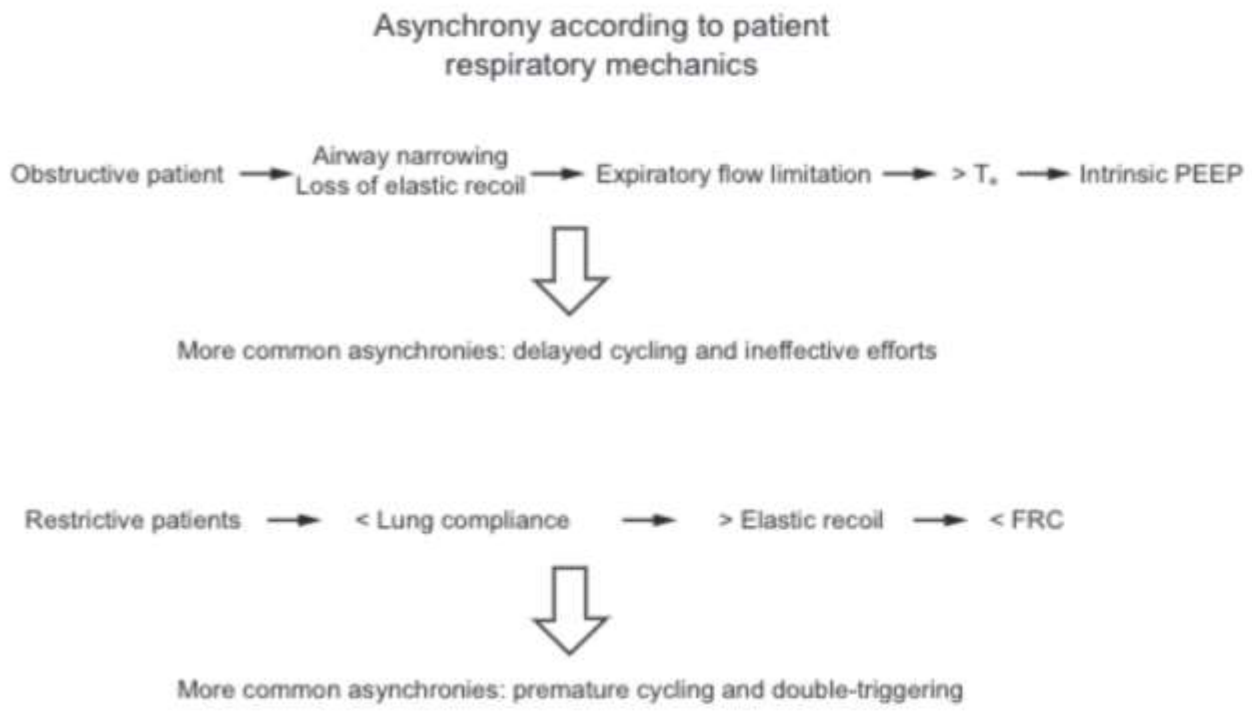


Fig. 2. Asynchronies are common in both obstructive and restrictive patients, although alterations of the underlying respiratory mechanics generate different types of asynchronies. FRC = functional residual capacity; T_e = expiratory time constant.

Modes of ventilation and patient-ventilator interactions

Pressure control vs volume control mode

- Pressure control mode reduced dys-synchronies more than the volume control mode at the set tidal volume of 6 ml/kg and 7.5 ml/kg in 19 mechanically ventilated ARDS patients, but at risk of lung injury. The inspiratory flow in pressure control mode at 50% and 75% of inspiratory time was higher in the pressure control mode compared to volume control mode when the set tidal volume and other parameters are matched in another study of 19 patients with ARDS or at risk of ARDS. Adjusting flow pattern in volume control mode (square form) can meet the flow demand of the patient

- Pressure control mode was better than volume control mode in terms of meeting variable inspiratory flow demand and reducing work of breathing in a study of 18 patients of ALI/ARDS who are mechanically ventilated

Figueroa-Casas JB et al., Effect of Tidal Volume Size and Its Delivery Mode on Patient-Ventilator Dyssynchrony. Ann Am Thorac Soc. 2016 Dec;13(12):2207-2214.
Figueroa-Casas JB et al.,Difference in inspiratory flow between volume and pressure control ventilation in patients with flow dyssynchrony. J Crit Care. 2017 Dec;42:264-267.
Kallet RH et al., The effects of pressure control versus volume control assisted ventilation on patient work of breathing in acute lung injury and acute respiratory distress syndrome. Respir Care. 2000 Sep;45(9):1085-96. Erratum in: Respir Care. 2000 Nov;45(11):1416.

PSV mode and PAV mode

- Obstructive and restrictive disease pattern was associated with delayed and premature cycling respectively regardless of whether pressure support mode or proportional assist mode in a experimental study. Trigger delay was lesser with PAV
- PAV with appropriate flow or volume assist can better reduce inspiratory work load and cycling synchrony when compared to PSV in a experimental study with lung simulator model

Vasconcelos RS et al.,Influences of Duration of Inspiratory Effort, Respiratory Mechanics, and Ventilator Type on Asynchrony With Pressure Support and Proportional Assist Ventilation. Respir Care. 2017 May;62(5):550-557.
Chen Y et al.,Comparison of Inspiratory Effort, Workload and Cycling Synchronization Between Non-Invasive Proportional-Assist Ventilation and Pressure-Support Ventilation Using Different Models of Respiratory Mechanics. Med Sci Monit. 2019 Nov 28;25:9048-9057.

PSV with auto cycling

- PSV with auto cycling and trigger mode can reduce micro dysynchrony better than macro dysynchornies without affecting the breathing pattern and workload as demonstrated in 24 patients in a study
- Breathing pattern, patient discomfort and reduction of expiratory Asynchrony improved overall with adoption of the PSV mode with auto cycling in a study of 16 patients
- In a study of 15 difficult to wean patients, PSV with autocycling has reduced trigger delay from 407 ms to 59 ms and ineffective efforts from 12.5% to 2.8% in comparison with pre-fixed cycling with better synchronisation with patient effort

Liu L et al., Automatic Adjustment of the Inspiratory Trigger and Cycling-Off Criteria Improved Patient-Ventilator Asynchrony During Pressure Support Ventilation. Front Med (Lausanne). 2021 Nov 12;8:752508

Hoff FC et al.,Cycling-off modes during pressure support ventilation: effects on breathing pattern, patient effort, and comfort. J Crit Care. 2014 Jun;29(3):380-5

Mojoli F et al.,Waveforms-guided cycling-off during pressure support ventilation improves both inspiratory and expiratory patient-ventilator synchronisation. Anaesth Crit Care Pain Med. 2022 Dec;41(6):101153.

NAVA ventilation mode

- In terms of patient ventilator interactions, NAVA mode of ventilation when compared with pressure support mode reduced the overall incidence of asynchrony index both in invasive and non-invasive ventilation in 331 patients of respiratory failure. Reduction of auto triggering and pre-mature triggering were better.
- By better inspiratory effort synchrony, NAVA can helps in weaning of the IMV patients
- In NAVA-NICE trial conducted on 40 patients, NAVA reduced asynchrony events in non-invasively ventilated COPD patients compared to PSV mode without affecting the rate of NIV failure
- NAVA reduced trigger delay by 60% and 40% and cycling dys-synchrony to almost nil in COPD and ARDS in a study of 24 patients

Chen C et al.,Neurally adjusted ventilatory assist versus pressure support ventilation in patient-ventilator interaction and clinical outcomes: a meta-analysis of clinical trials. Ann Transl Med. 2019 Aug;7(16):382.
Ferreira JC et al.,Neurally Adjusted Ventilatory Assist (NAVA) or Pressure Support Ventilation (PSV) during spontaneous breathing trials in critically ill patients: a crossover trial. BMC Pulm Med. 2017 Nov 7;17(1):139.
Tajamul S et al.,. Neurally-Adjusted Ventilatory Assist Versus Noninvasive Pressure Support Ventilation in COPD Exacerbation: The NAVA-NICE Trial. Respir Care. 2020 Jan;65(1):53-61.

Adaptive support ventilation versus biphasic positive airway pressure in patients with acute exacerbation of chronic obstructive pulmonary disease

Amr A. Elmorsy, Bassem N. Beshay, Emad H. Mousa

Patients and methods

This double-blind randomized trial was conducted on 72 AECOPD adult patients admitted to the units of Critical Care Medicine Department in Alexandria Main University Hospital indicated for invasive mechanical ventilation. Patients were excluded for reasons such as pregnancy, hemodynamic instability, and severe neurological disease. They were categorized randomly as follows: group I included 36 patients who were ventilated using the BIPAP mode and group II included 36 patients who were ventilated using the ASV mode. Informed consent was obtained from patients' first of kin after approval from the Ethical Committee of Alexandria Faculty of Medicine. Ventilatory parameters (respiratory rate, tidal volume, peak airway pressure, and rapid shallow breathing index) and lung mechanics (static compliance and inspiratory resistance) were recorded. Patient ventilator dys-synchrony and asynchrony index were recorded daily. Days of mechanical ventilation, ICU stay, and mortality were calculated.

Results

In the ASV group, the respiratory rate was significantly lower, tidal volume was higher, and rapid shallow breathing index was lower. Significantly higher compliance and lower resistance were encountered in the ASV group, with better patient–ventilator synchronization. A significant reduction in days of mechanical ventilation in the ASV group was found with less ICU length of stay.

Table 3 Comparison between the two groups studied according to the asynchrony index

Asynchrony index range (%)	Volume control (first 2 h) [*n* (%)]	Day 1 [*n* (%)]	Day 2 [*n* (%)]
BIPAP (group I)	36 (100)	36 (100)	36 (100)
0–5	3 (8.3)	4 (11.1)	4 (11.1)
5–10	2 (5.6)	5 (13.9)	3 (8.3)
>10	0 (0.0)	7 (19.4)	6 (16.7)
ASV (group II)	36 (100)	36 (100)	36 (100)
0–5	2 (5.6)	5 (13.9)	1 (2.8)
5–10	1 (2.8)	3 (8.3)	0 (0.0)
>10	0 (0.0)	1 (2.8)	0 (0.0)
P	–	$\chi^2 = P = 0.024^*$	FE = $P = 0.025^*$

ASV, adaptive support ventilation; BIPAP, biphasic positive airway pressure; FE, Fisher's exact test; *Statistically significant at $P \leq 0.05$.

Elmorsy et al., Adaptive support ventilation versus biphasic positive airway pressure in patients with acute exacerbation of chronic obstructive pulmonary disease. Research and Opinion in Anesthesia and Intensive Care 2(2):p 34-42, Apr–Jun 2015.

Thank you