

SCALARS AND LOOPS IN MECHANICAL VENTILATION

Presenter

Dr. Gaurav Sarnaik

OUTLINE

- Scalar
 - Pressure
 - Flow
 - Volume
- Recognizing Altered Physiological States
- Ventilator Alarms
- Loops

SCALARS

Real-Time graphical representation of a variable

Vertical Axis – Pressure, Volume, Flow

Horizontal Axis – Time

Measured Parameters –

- Pressure
- Flow

Derived Parameters –

- Volume (From Flow)

BASIC WAVEFORMS

PRESSURE



Rectangular



Exponential (rise)

VOLUME



Ascending ramp



Sinusoidal

FLOW



Rectangular



Sinusoidal



Ascending ramp



Descending ramp



Exponential (decay)

J.M. Cairo. Pilbeam's Mechanical Ventilation. Elsevier, New York, 2024

Flow Scalars

Waveform depends on:

1. Mode
2. Settings
3. Type of Breath

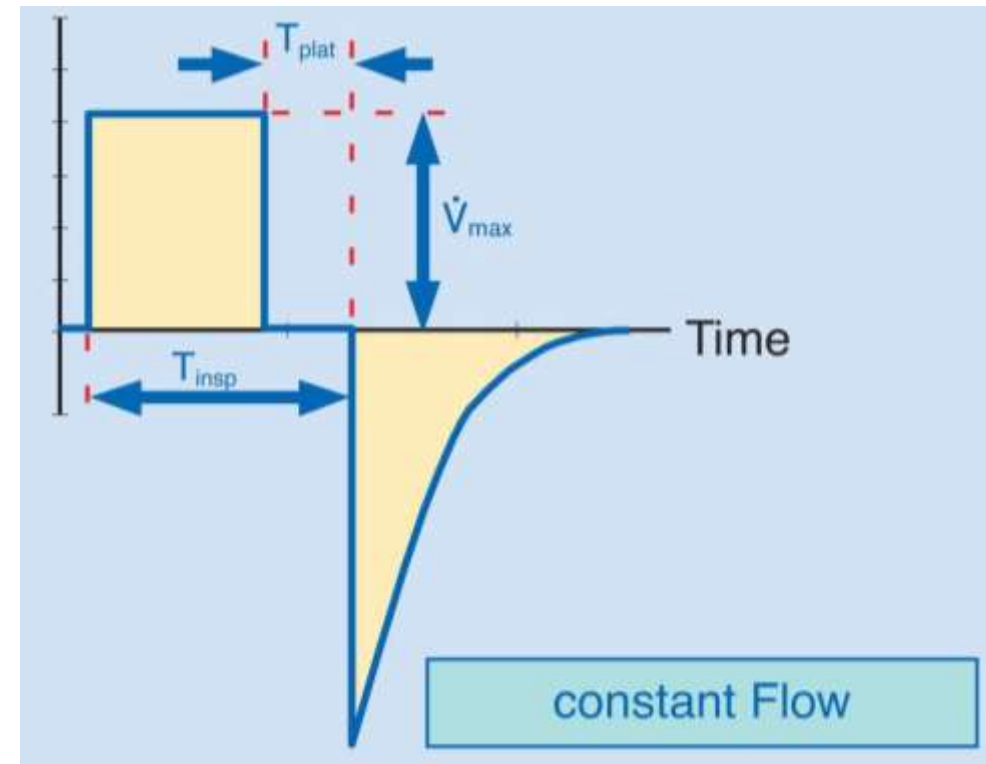
Inspiratory Flow

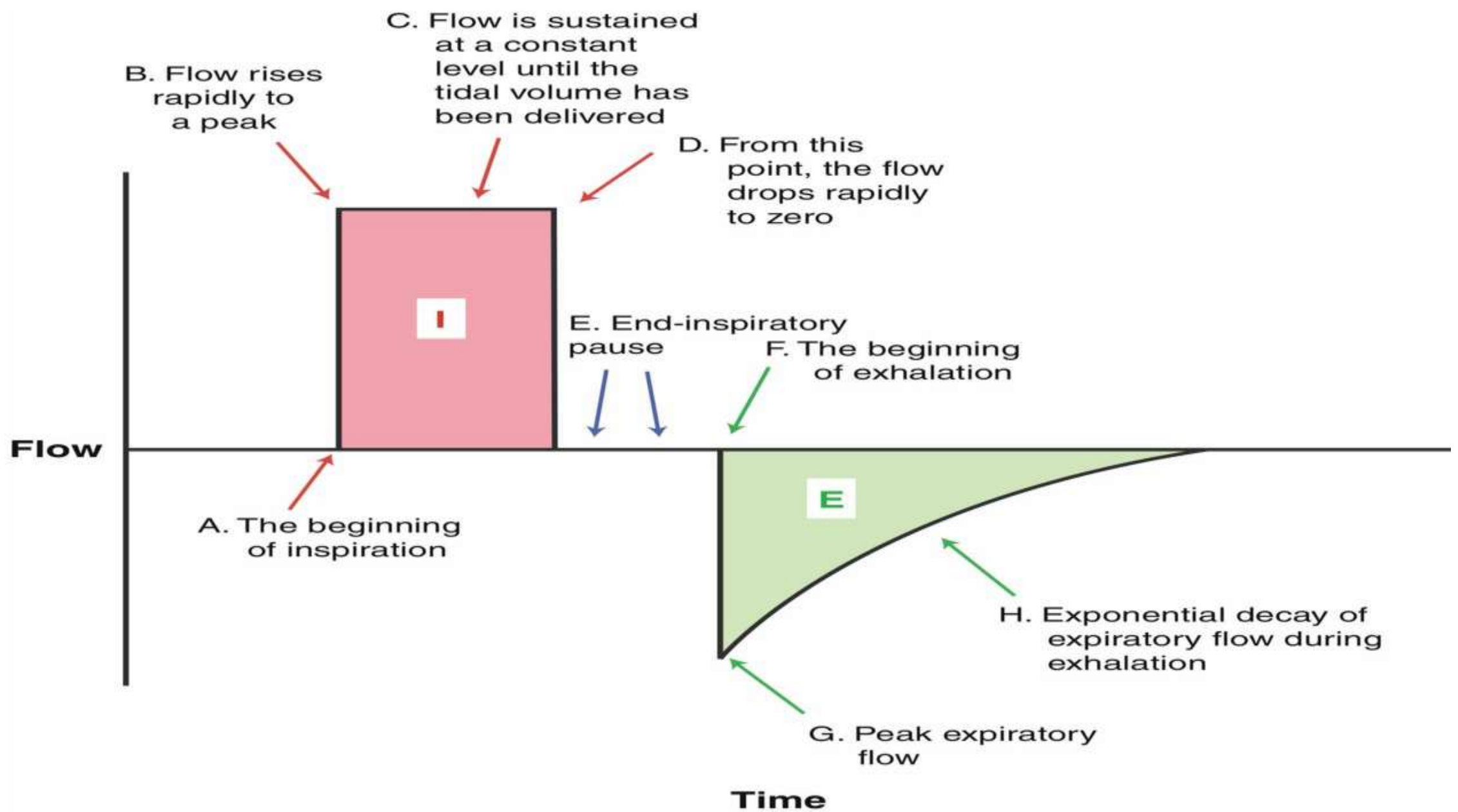
- Positive
- Active in Nature

Expiratory Flow

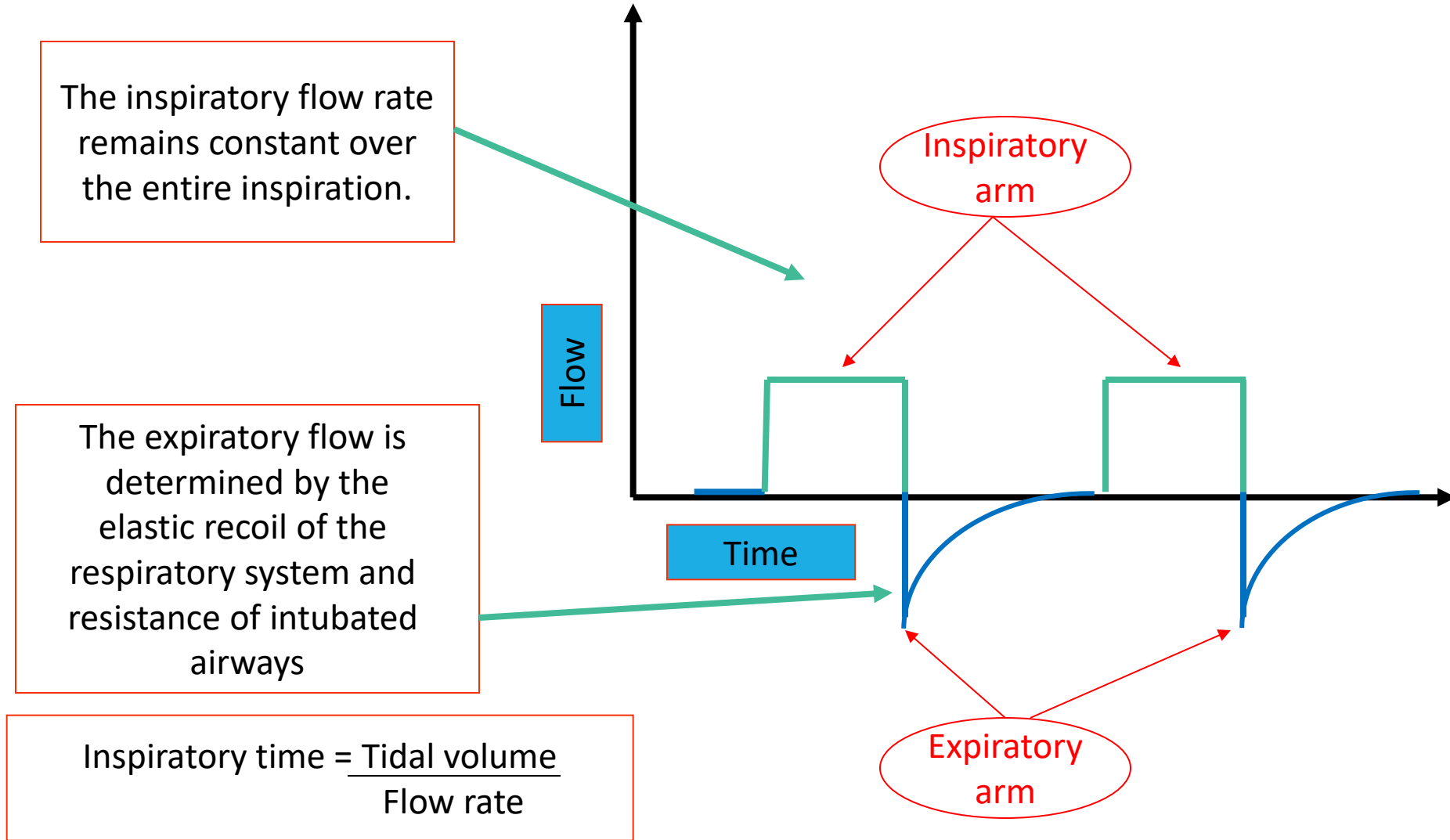
- Negative
- Passive – Depends on Elastic Recoil and Resistance of Lungs
- Active – Patient Efforts

PROTOTYPE: SQUARE WAVEFORM





The 'square wave' Flow Pattern

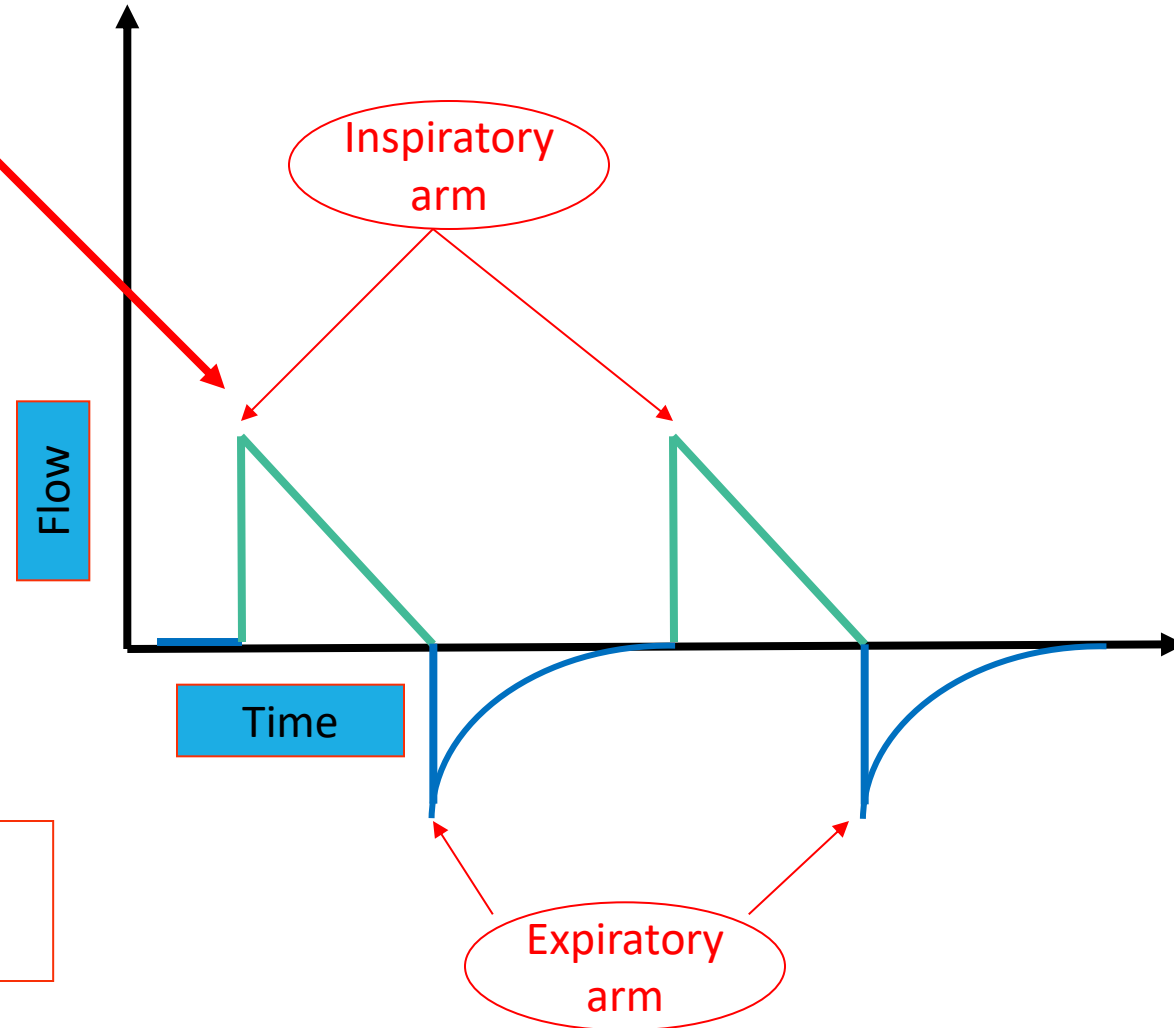


The 'decelerating ramp' flow pattern

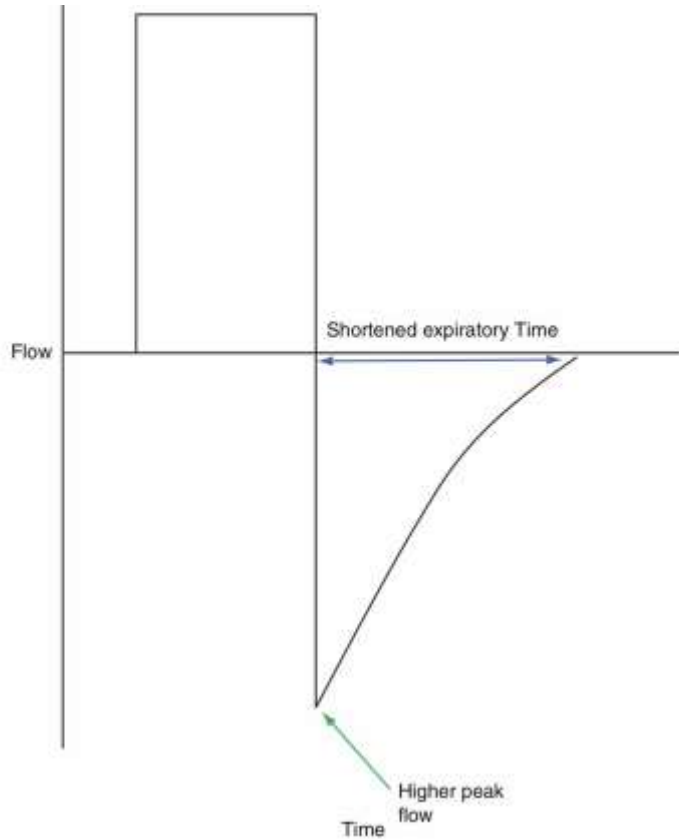
The inspiratory flow rate decelerates as a function of time to reach zero flow at end inspiration

For a given tidal volume, the inspiratory time is longer in this type of flow pattern as compared to the square wave pattern

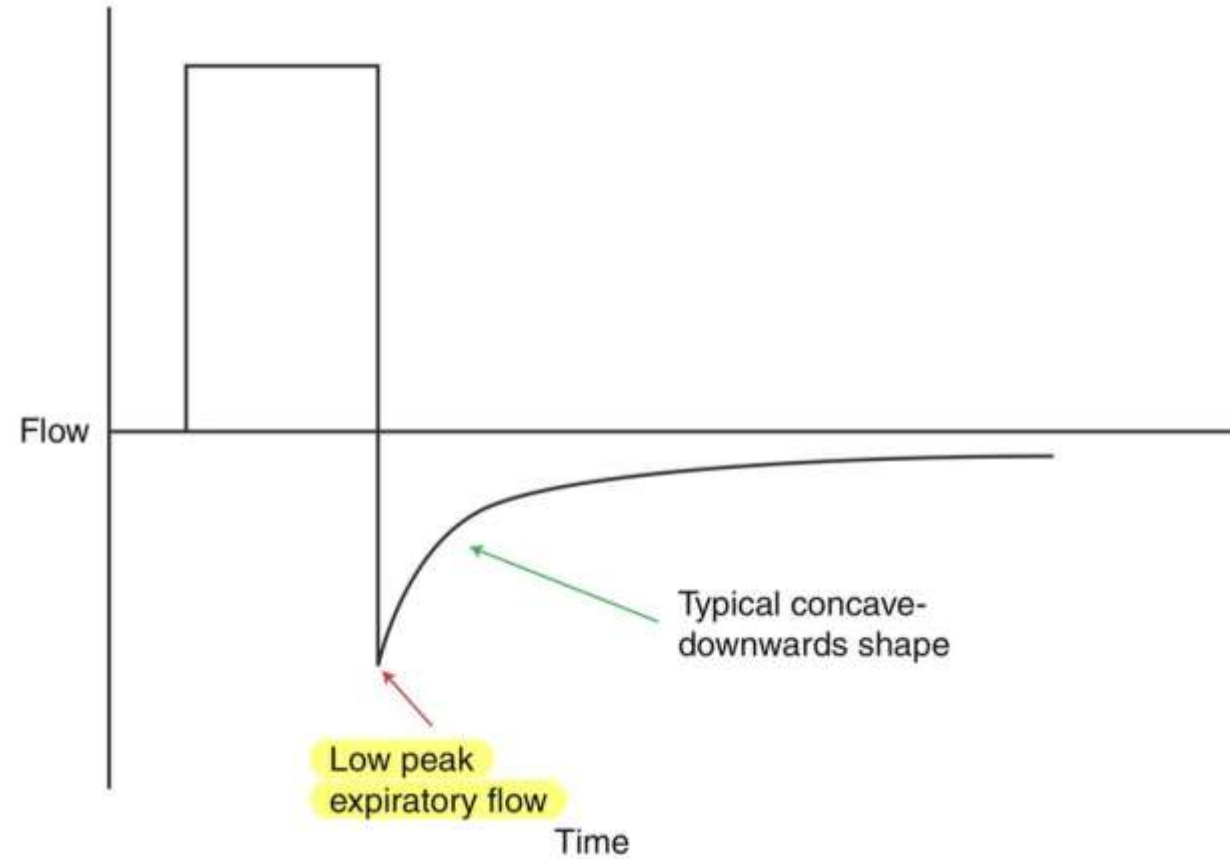
$$\text{Inspiratory time} = \frac{\text{Tidal volume}}{\text{Flow rate}}$$



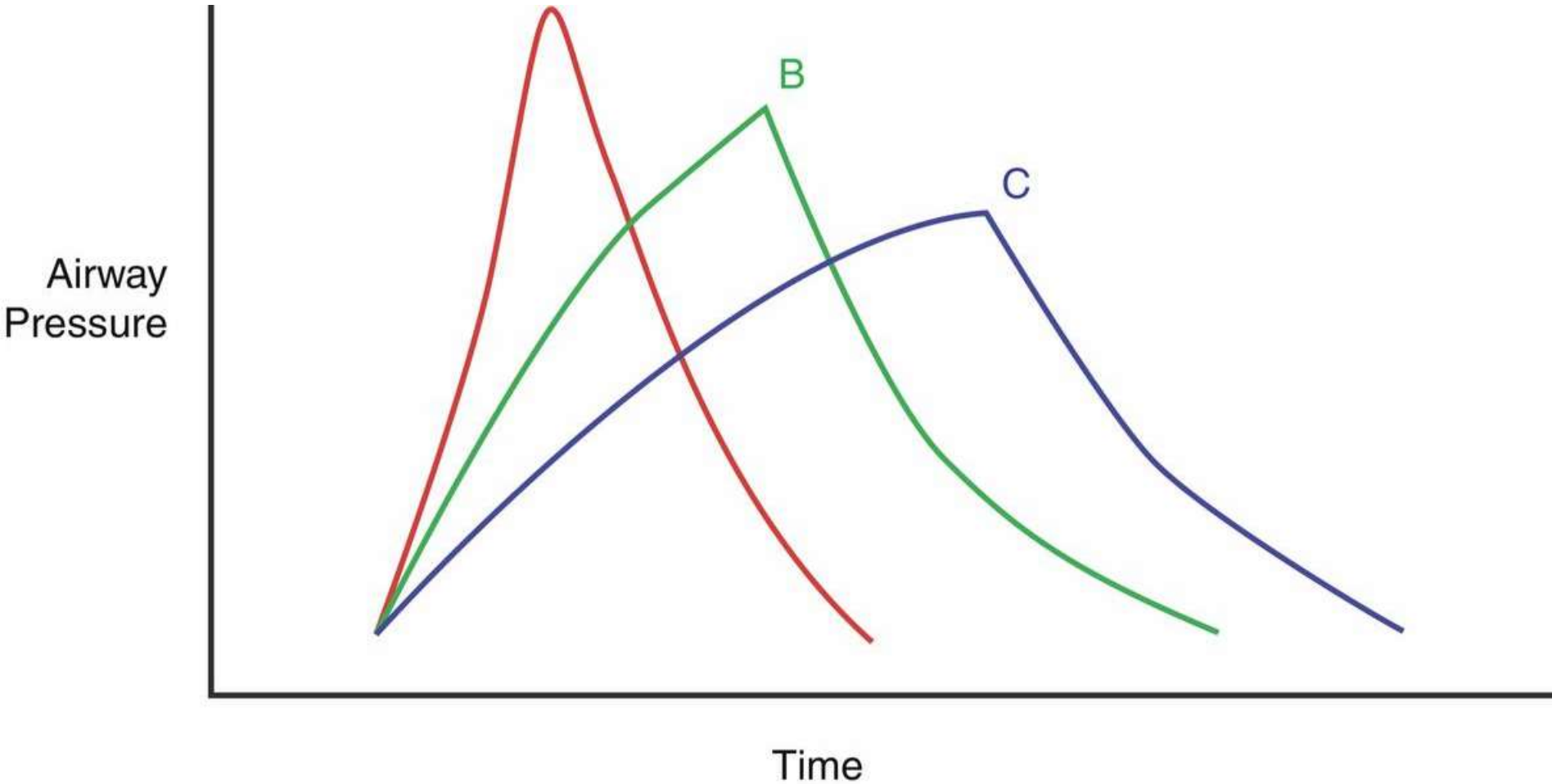
ARDS

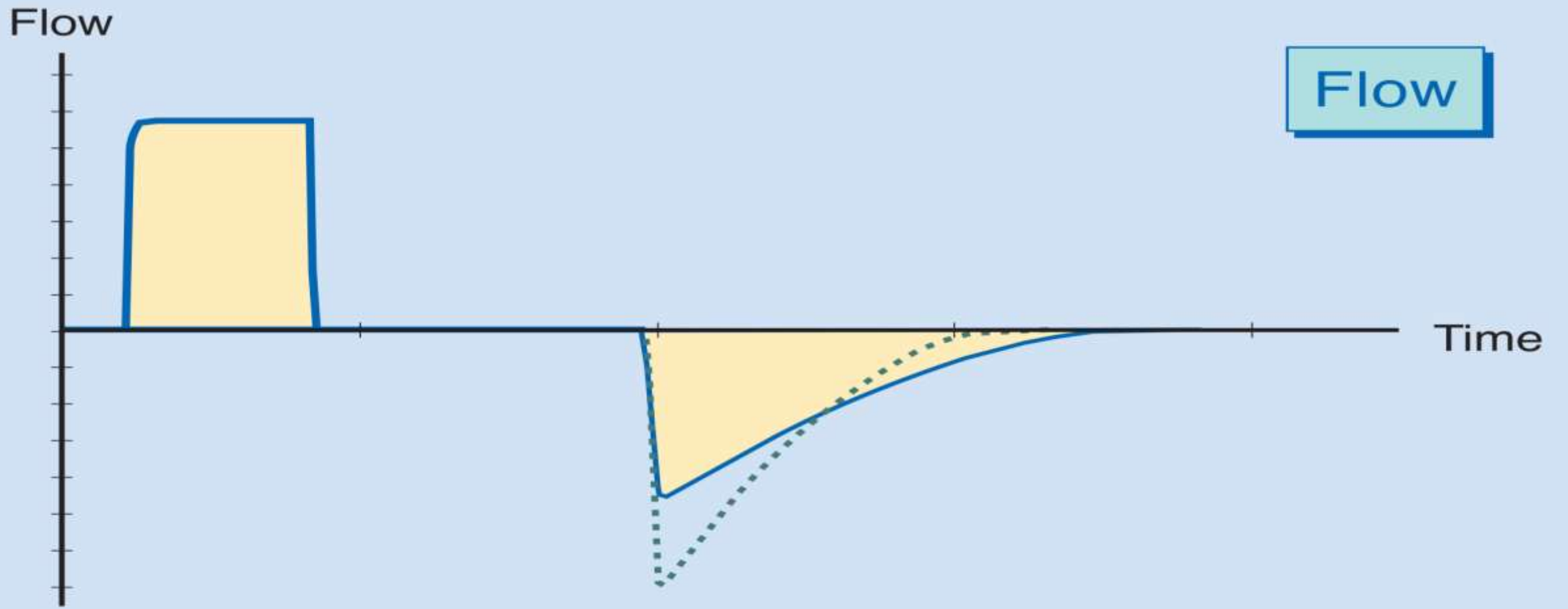


Airway Obstruction



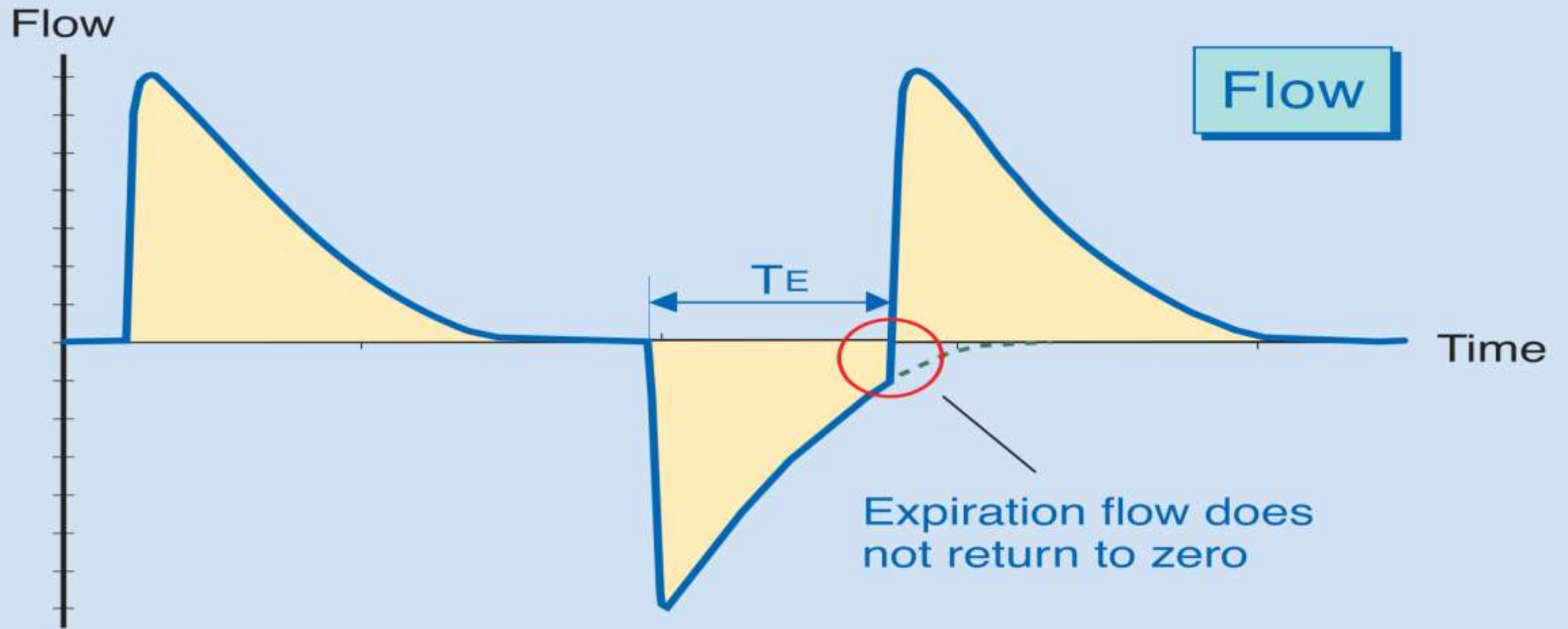
Effect of Flow Rate on Airway Pressure





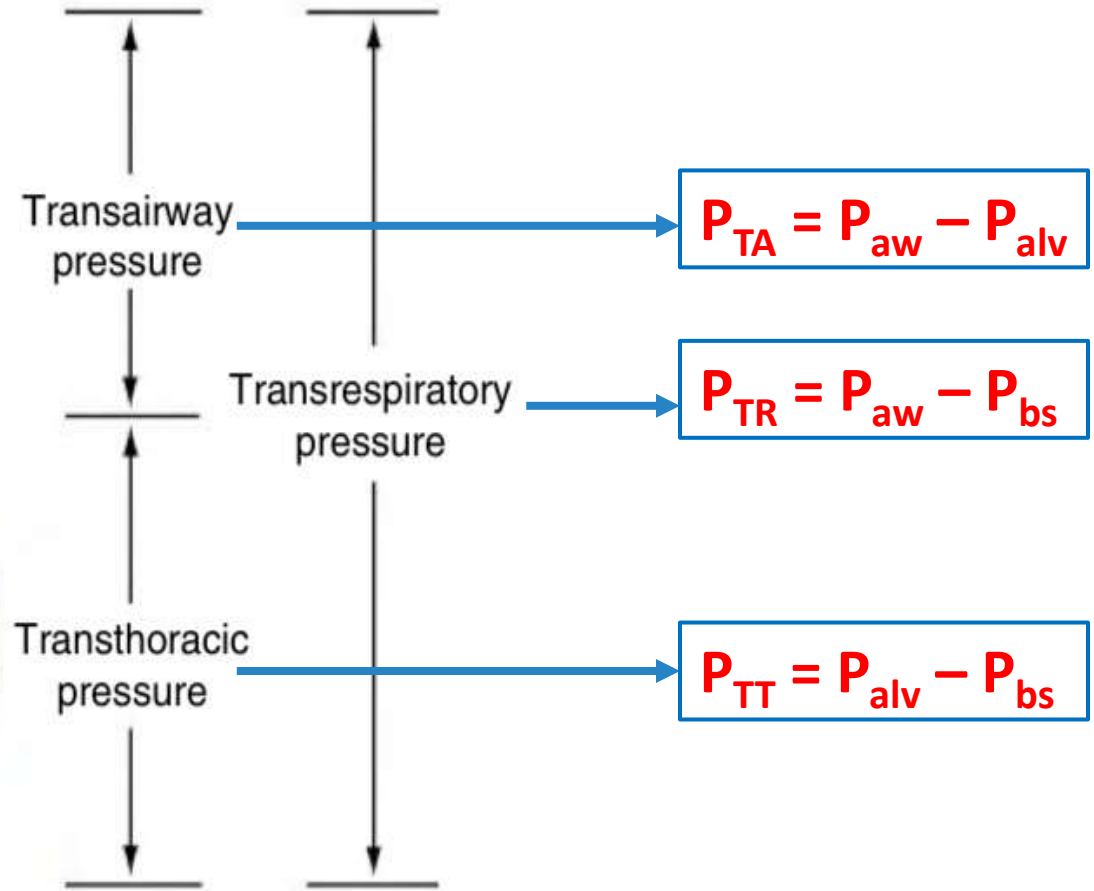
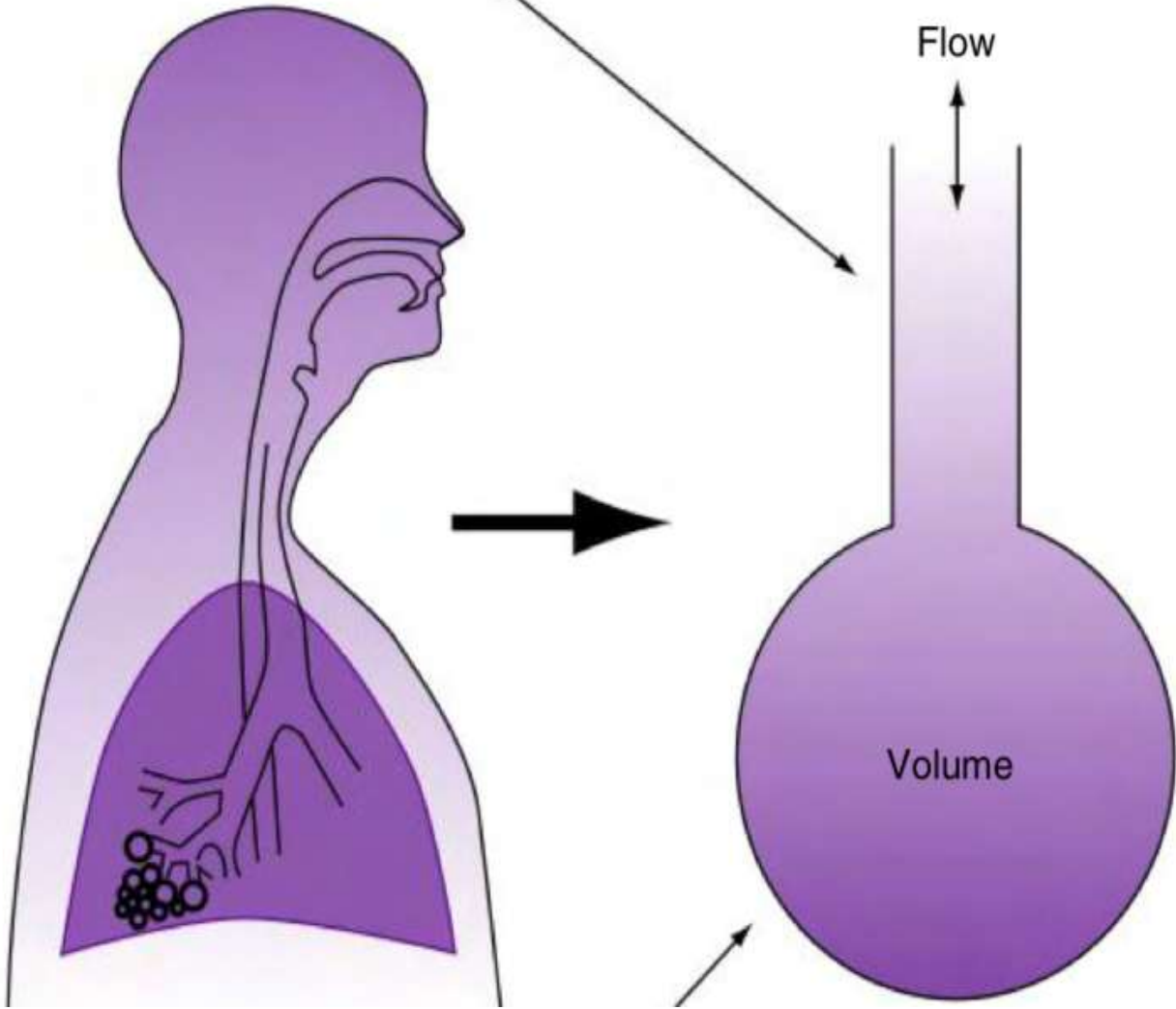
Increased Expiratory Resistance

Basics. In: Jean Michel Arnal, Robert Chatburn, *Monitoring Mechanical Ventilation Using Ventilator Waveforms*. 1st ed; Cham, Switzerland; Springer; 2018. pg. 1



Insufficient Expiration Time

$$\text{Resistance} = \frac{\Delta \text{Transairway pressure}}{\Delta \text{Flow}}$$



J.M. Cairo. Pilbeam's Mechanical Ventilation. Elsevier, New York, 2024

Equation of Motion

ventilation pressure = **elastic pressure** + **resistive pressure**
(to deliver tidal volume) (to inflate lungs and chest wall) (to make air flow through the airways)

$$P_{\text{mus}} + P_{\text{vent}} = P_{\text{elastic}} + P_{\text{resistive}}$$

$$P_{\text{mus}} + P_{\text{vent}} = E \times V + R \times V$$

Airway Opening Pressure (P_{awo})

Syn:

Airway pressure (P_{aw}),
Mouth pressure (P_M),
Upper airway pressure,
proximal airway pressure,
mask pressure

- This is the pressure applied at the airway opening (mouth or the patient tube)
- In the absence of positive pressure breathing (through endotracheal tube, tracheostomy tube or noninvasively by mask), the P_{aw} is equal to atmospheric pressure

Body surface pressure (P_{bs})

- The pressure at the body surface
- Again this pressure is equal to atmospheric pressure unless the patient's body is subjected to negative pressure

Intrapleural pressure (P_{pl})

- The pressure within the pleural space
- During spontaneous breathing this is normally, minus 5cm H₂O at end-exhalation, and minus 10 cm H₂O at end-inspiration.
- The surrogate measurement for P_{pl} is esophageal pressure (P_{es}) which can be measured using an esophageal balloon

Alveolar pressure (P_A or P_{ALV})

Syn:

Intrapulmonary pressure,
Lung pressure

- During spontaneous breathing, alveolar pressure is negative to the atmospheric pressure during inspiration (minus 1 cm H₂O), and positive to atmospheric pressure during exhalation (1 cm H₂O)

Trans-airway pressure (P_{TA})

The difference between the airway opening pressure (P_{awo}) and the alveolar pressure (P_{ALV}):

$$P_{TA} = P_{awo} - P_{ALV}$$

- It is the pressure responsible for driving the bulk flow through the airways.
- Produced by the resistance to airflow within the conducting airways.

Transpulmonary pressure (P_{TP})

Syn

Transalveolar pressure (P_A), Alveolar distending pressure: The difference between the alveolar pressure (P_{ALV}) and the intrapleural pressure (P_{PL}):

$$P_{TP} = P_{ALV} - P_{PL}$$

- The pressure required to distend the lung
- When P_{TP} increases, the lung distends
- P_{TP} can be made to increase by either increasing the P_{alv} (by positive pressure ventilation) or by decreasing the P_{PL} (by negative pressure ventilation).

Trans-Thoracic Pressure (P_w or p_{TT})

The difference between the alveolar pressure (P_{ALV}) and the body surface pressure (P_{bs}):

$$P_{TT} = P_{ALV} - P_{bs}$$

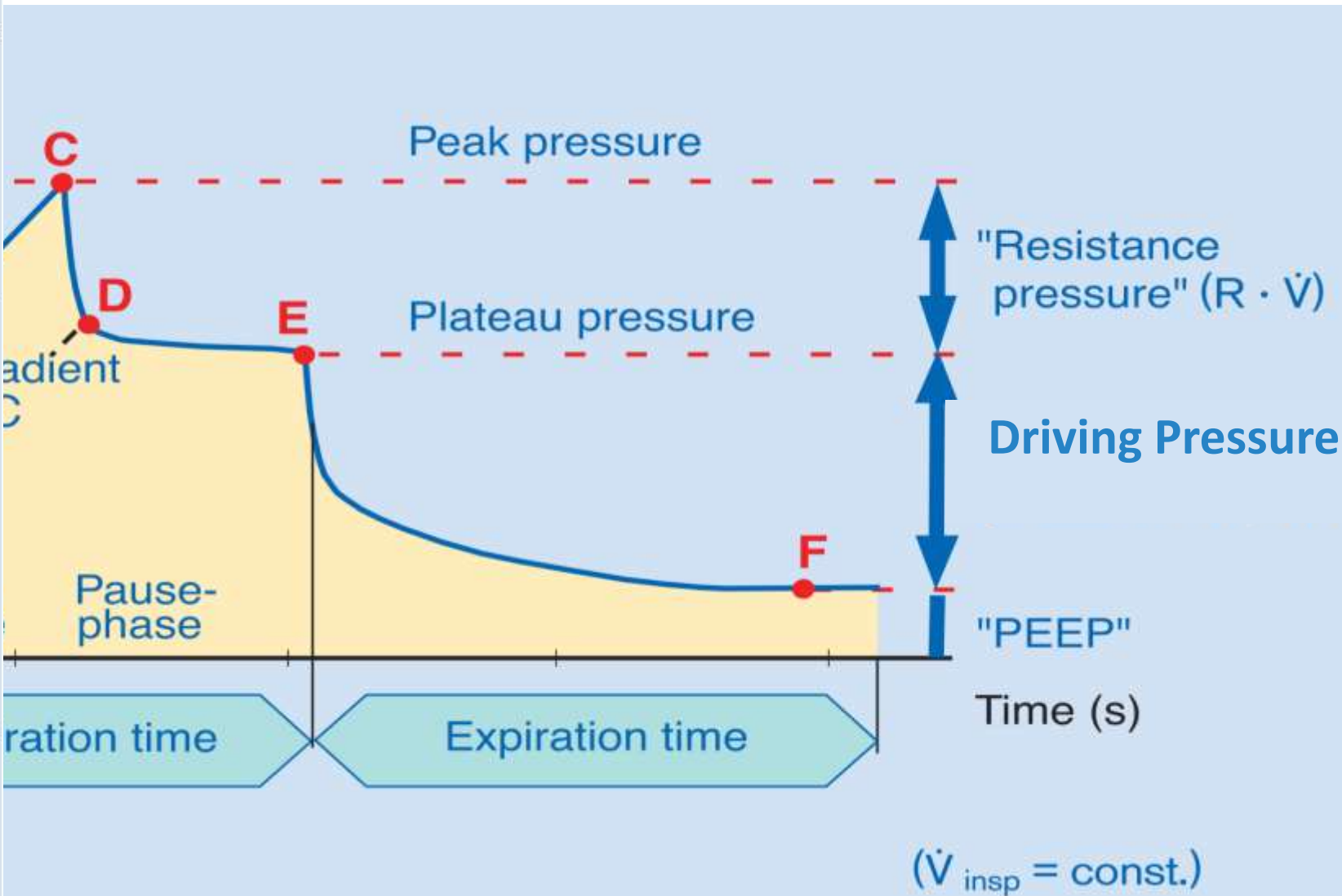
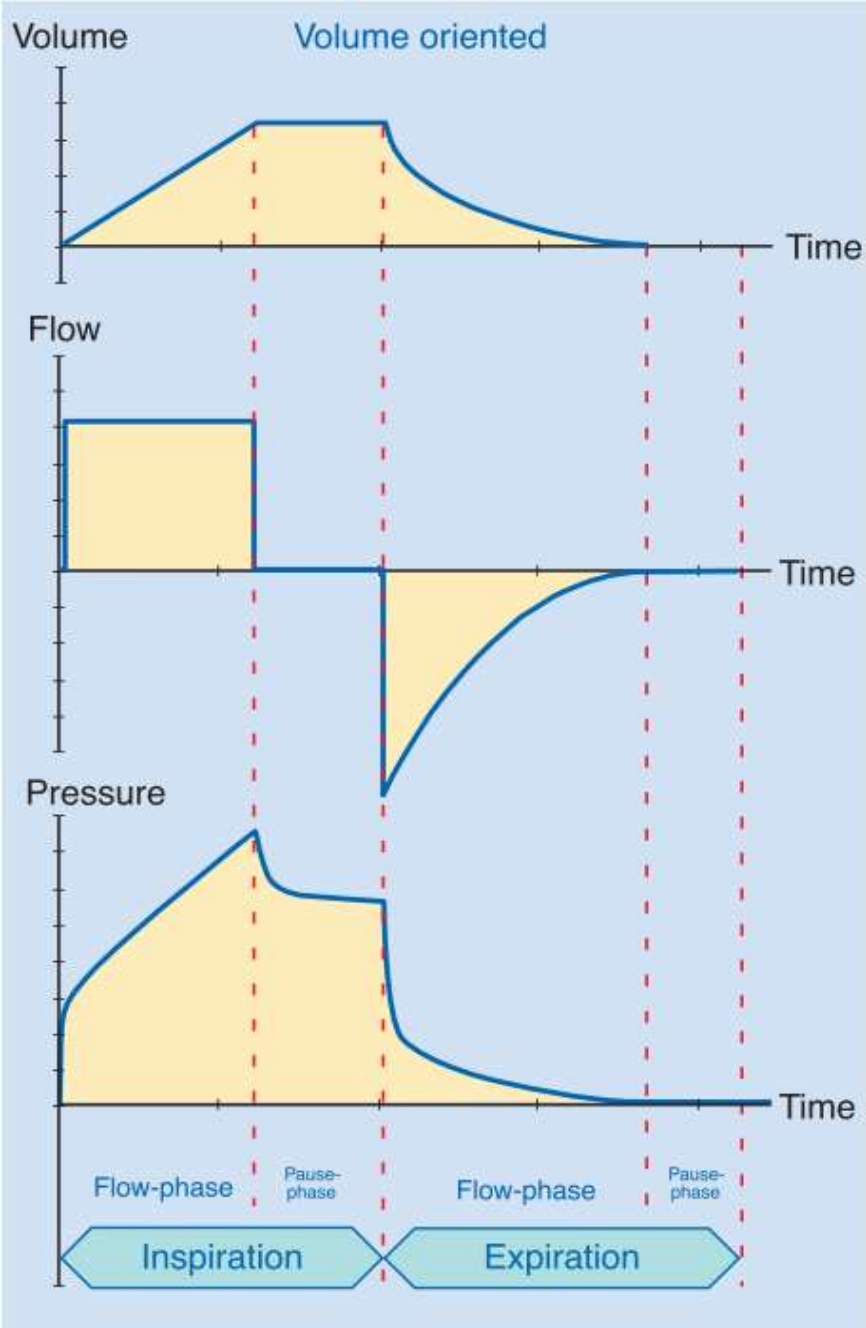
- It is the pressure required to distend the lungs along with the thoracic cage.

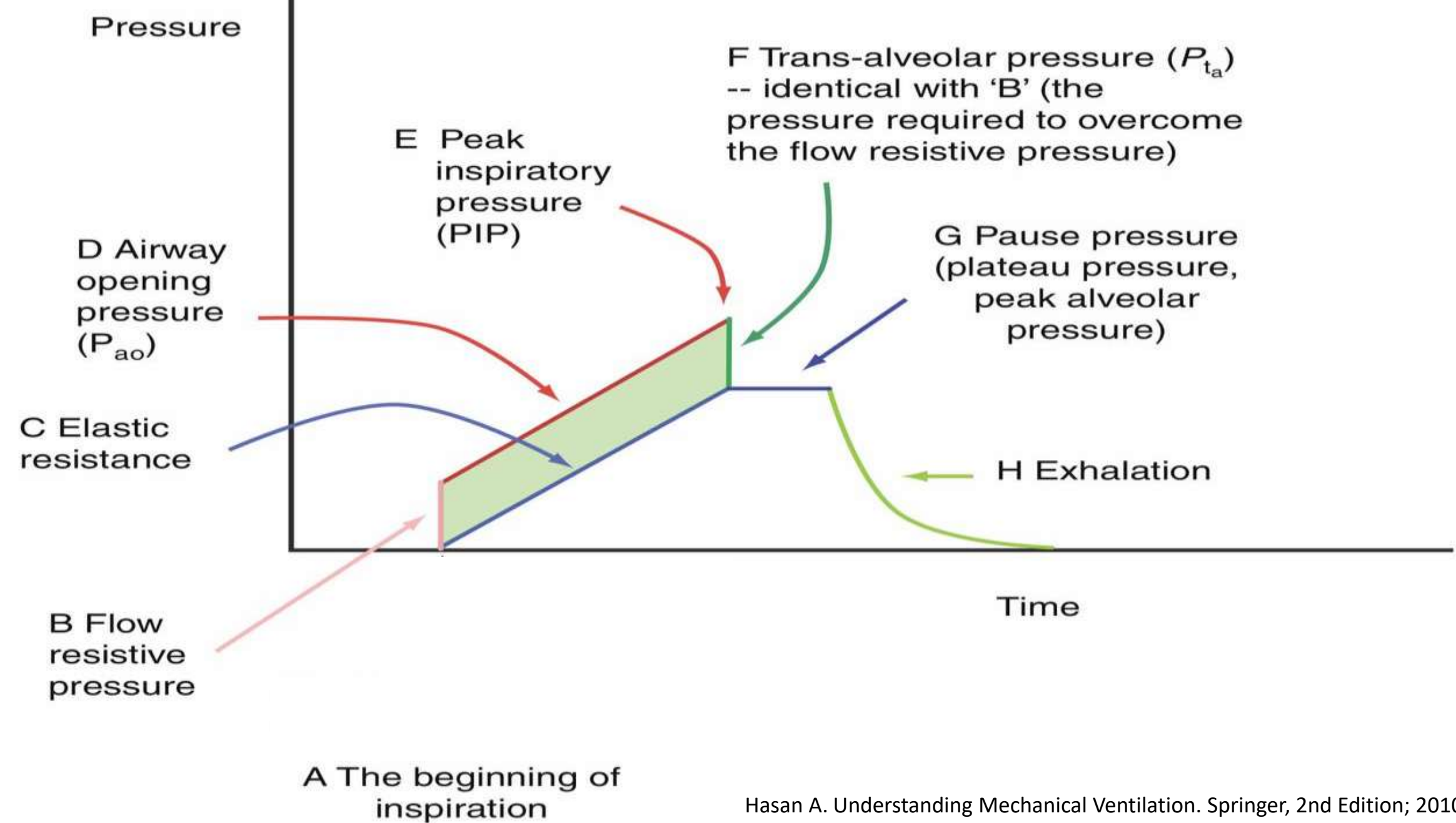
Transrespiratory-system pressure

The difference between the airway opening pressure (pressure at the mouth or patient tube) and the pressure at the body surface):

$$P_{TR} = P_{awo} - P_{bs}$$

- It is the pressure required to expand the lungs (pressure required to overcome elastance), and also to produce airflow (pressure required to overcome resistance).
- P_{TR} therefore has two components: Transairway pressure (P_{TA}) which performs the resistive work, and transthoracic pressure (P_{TT}) which performs the elastic work.





High airway resistance

Obstruction or kinking of the endotracheal tube
Excessive airway secretions
Bronchospasm
Clogged heat-moisture exchangers.

Low static compliance (stiff lung)

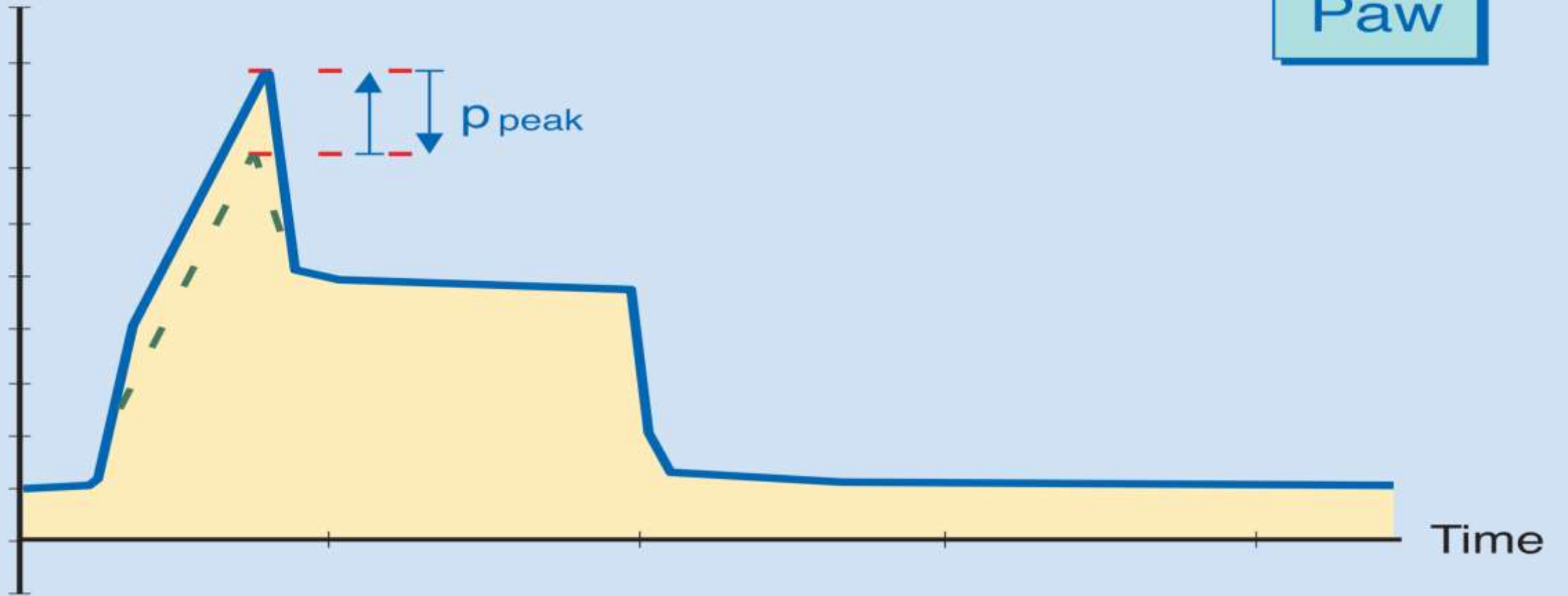
Pneumonic consolidation
ARDS
Pulmonary edema
Pleural effusions
Abdominal distension

Raised Peak Airway Pressure

Raised Plateau Pressure

Pressure

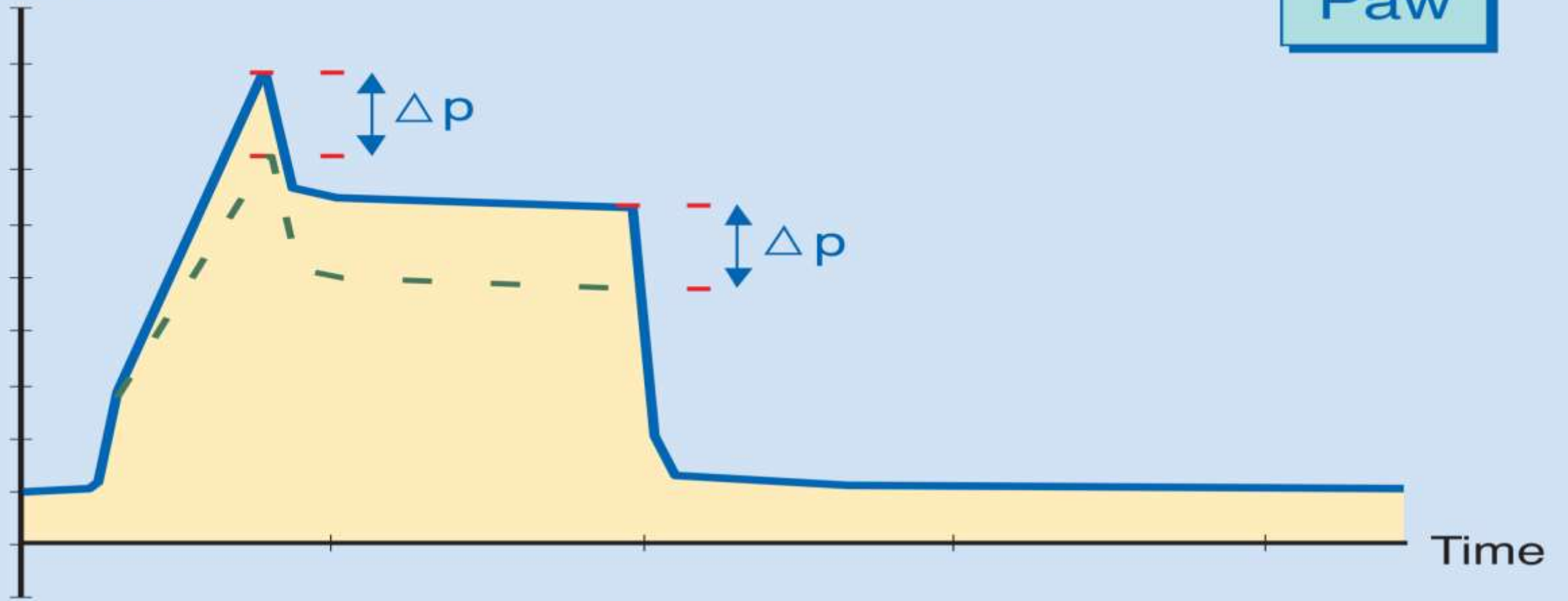
Paw



Increased Airway Resistance

Pressure

Paw



Decreased Compliance

STRESS INDEX

Dimensionless coefficient

Quantitatively describes shape of the Pressure time curve

Preinstalled Software for Calculation

- Macquet Servo-I
- Hamilton

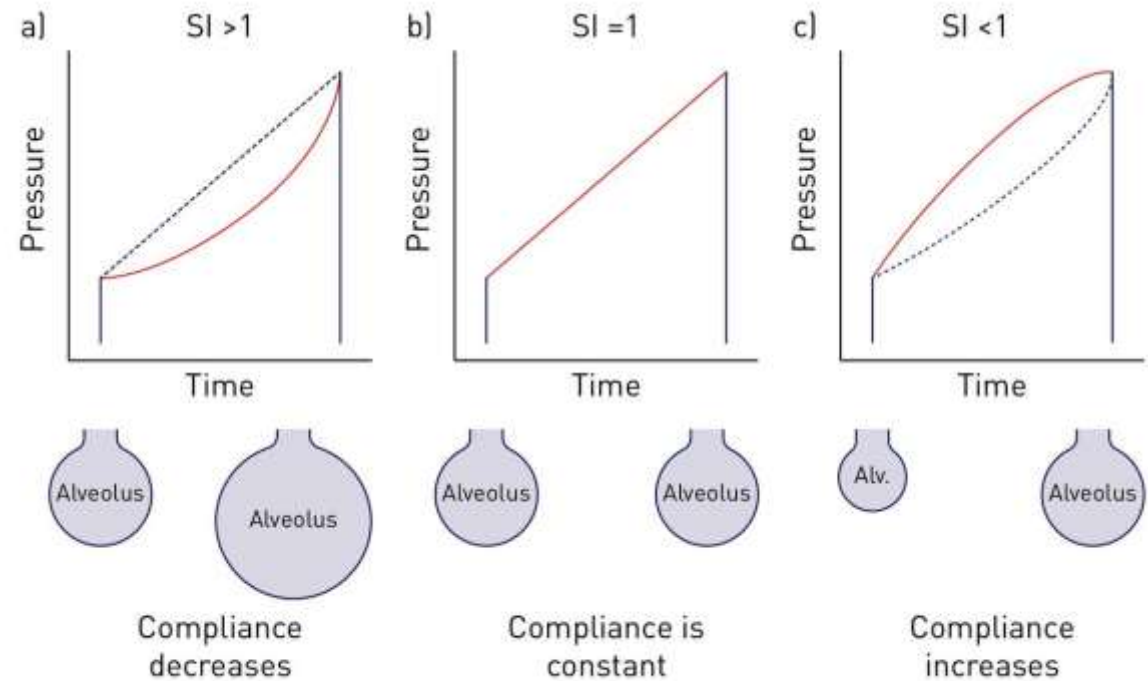


Figure 4. a) SI with overdistension, b) normal SI, and c) SI with tidal recruitment.

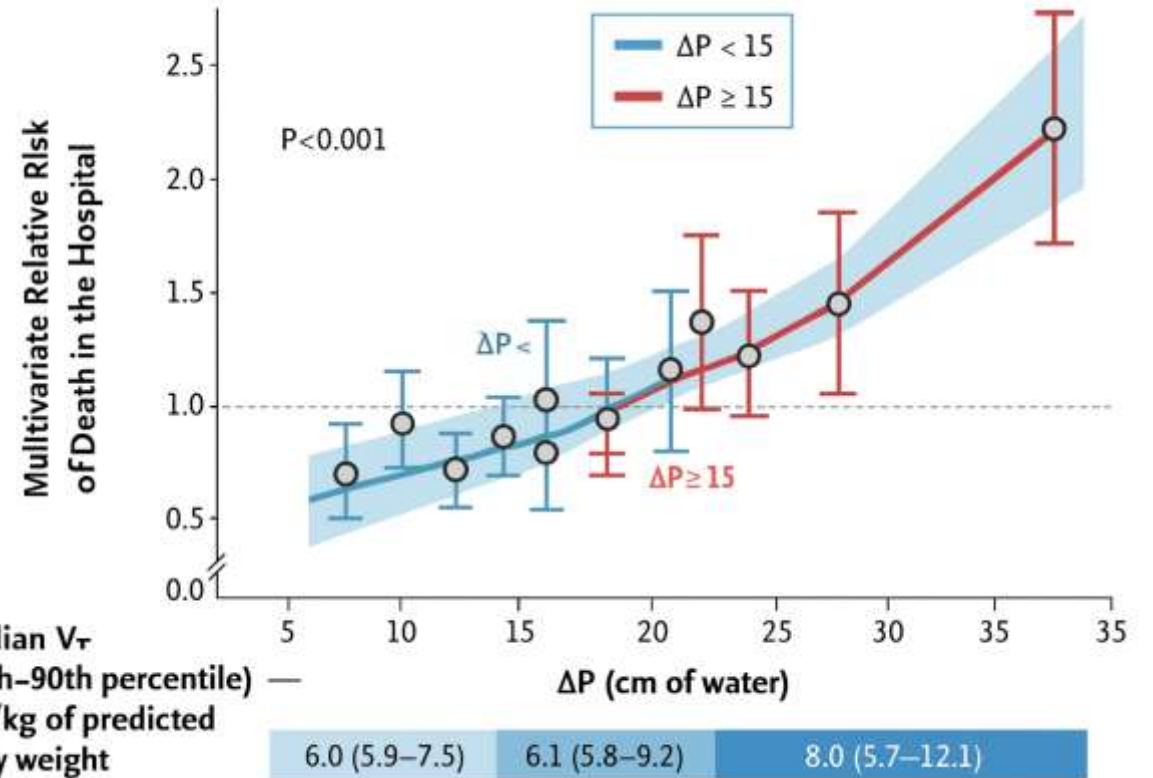
Driving Pressure

The NEW ENGLAND JOURNAL of MEDICINE

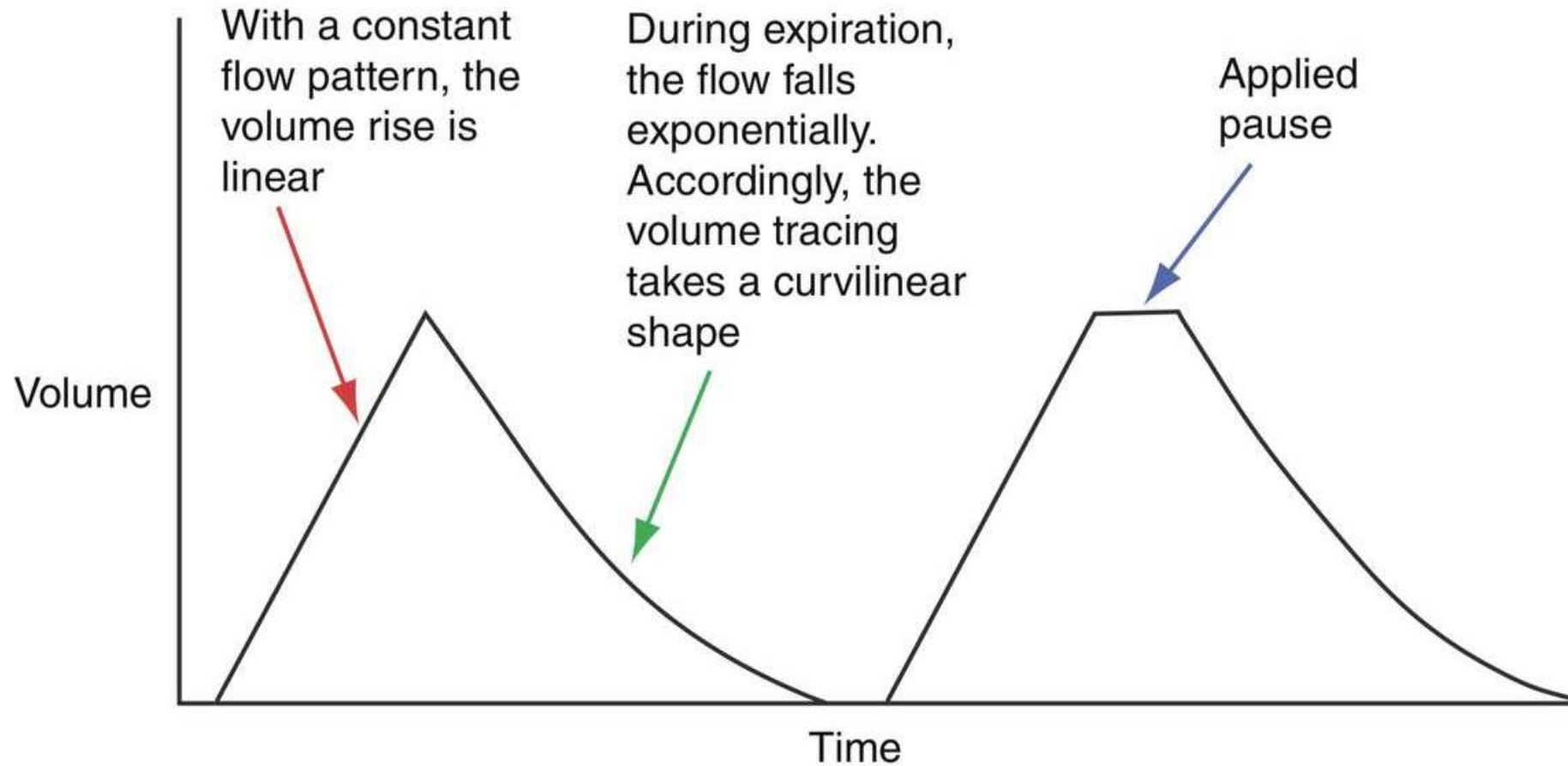
SPECIAL ARTICLE

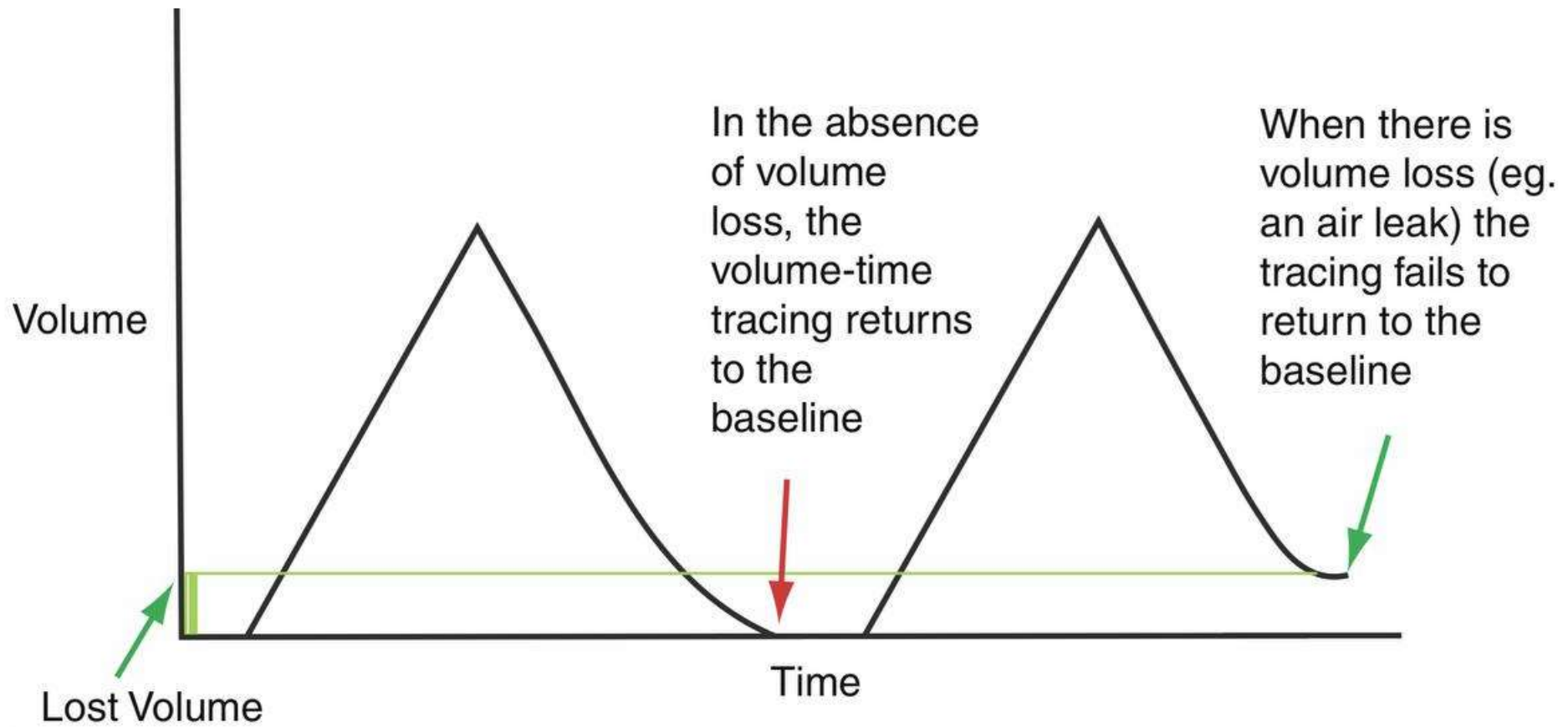
Driving Pressure and Survival in the Acute Respiratory Distress Syndrome

Marcelo B.P. Amato, M.D., Maureen O. Meade, M.D., Arthur S. Slutsky, M.D., Laurent Brochard, M.D., Eduardo L.V. Costa, M.D., David A. Schoenfeld, Ph.D., Thomas E. Stewart, M.D., Matthias Briel, M.D., Daniel Talmor, M.D., M.P.H., Alain Mercat, M.D., Jean-Christophe M. Richard, M.D., Carlos R.R. Carvalho, M.D., and Roy G. Brower, M.D.



Volume-Time Scalar





Static and Dynamic Parameters

Compliance

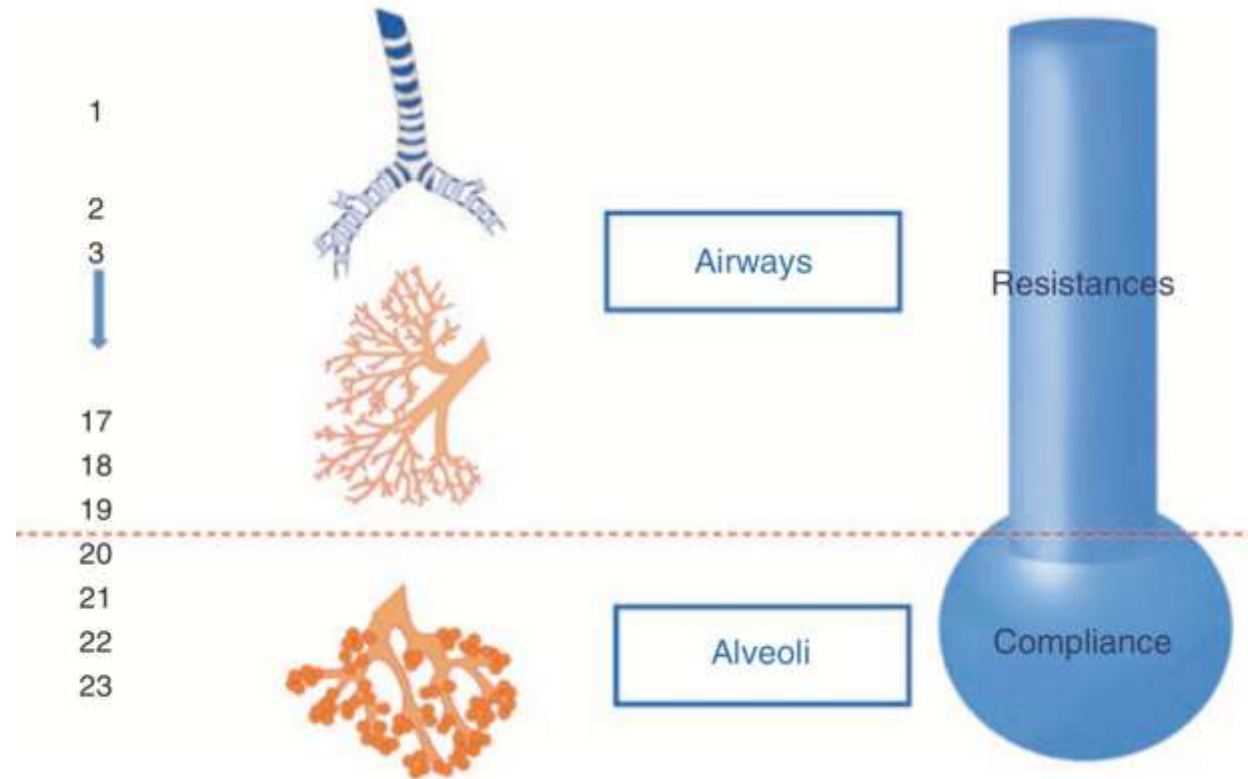
- $\Delta \text{ volume} / \Delta \text{ pressure}$

Resistance

- $\Delta \text{ pressure} / \Delta \text{ Flow}$

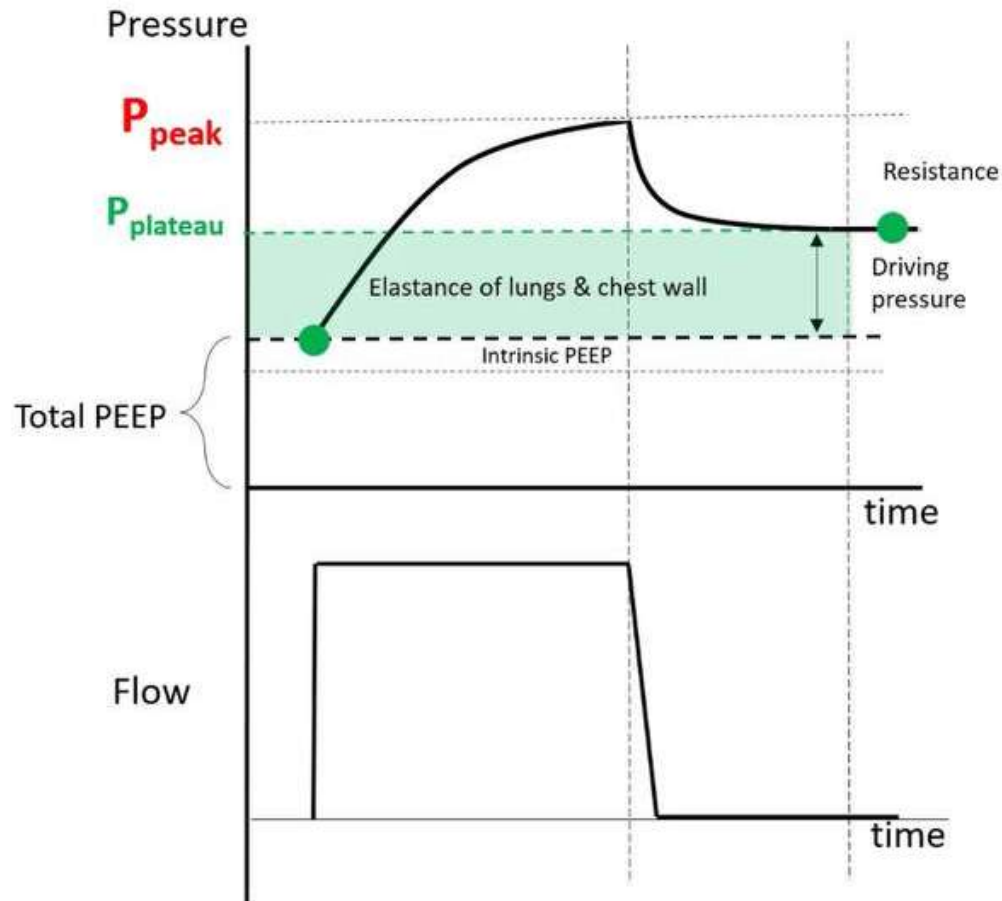
Elastance

- $\Delta \text{ pressure} / \Delta \text{ volume}$



Static compliance

measuring compliance with no airflow – complete stop.



$$C_{stat} = V_t / (P_{plat} - PEEP)$$

$$C_{dyn} = V_t / (PIP - PEEP)$$

Normal Compliance

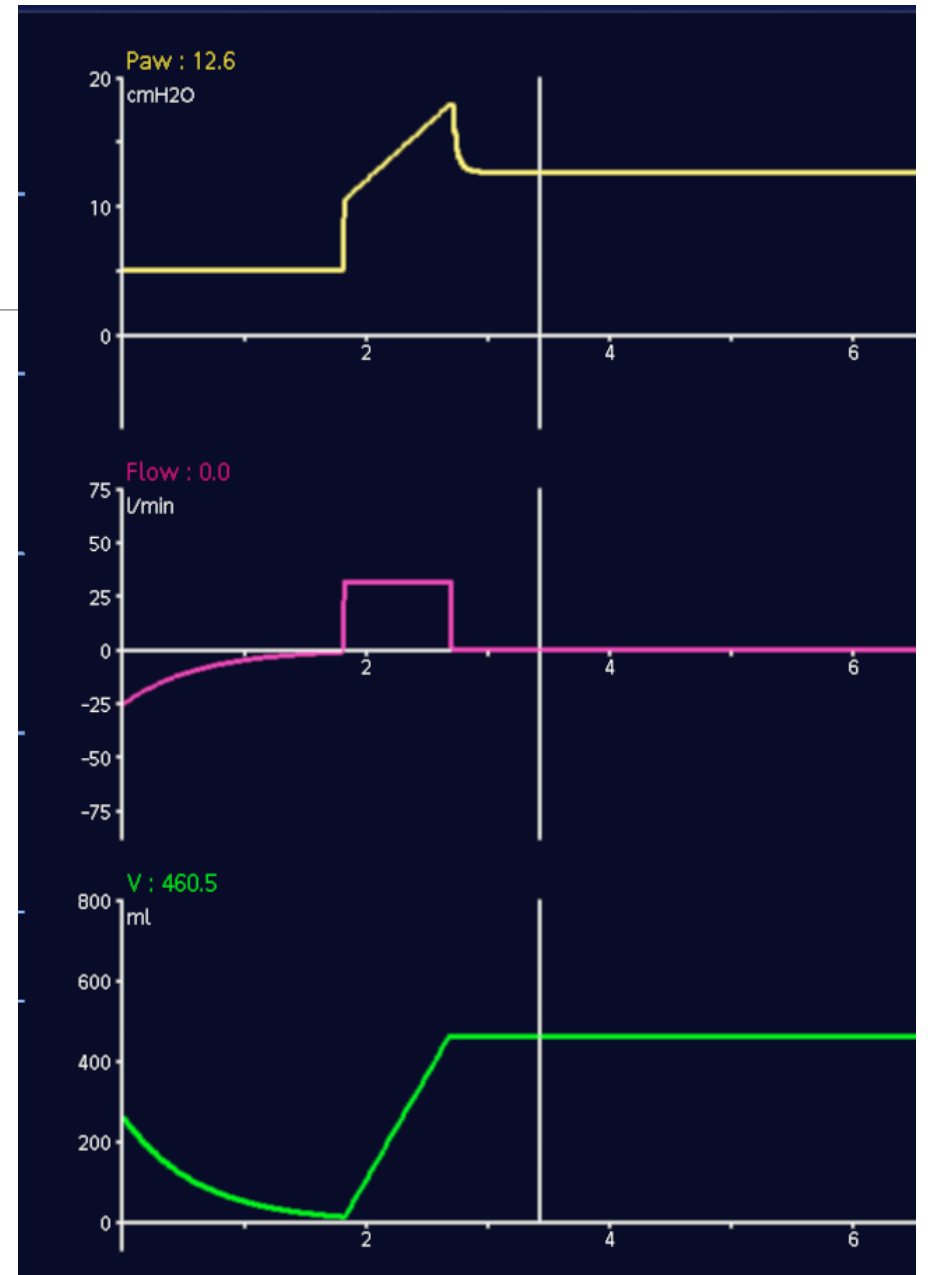
Males: 40 - 100 ml/cm H₂O

Females: 35 - 100 ml/cm H₂O

Pre-Requisites for Cstat Measurement

- VCV
- Ideally paralyzed
- Square Wave Form
- Inspiratory Hold
- Expiratory Hold

Inspiratory Hold



Exp. Hold



TABLE 3.1. Static and dynamic compliance in various lung conditions.

Lung condition	Dynamic compliance	Static compliance
Cardiogenic pulmonary Edema	Decreased	Decreased
ARDS	Decreased	Decreased
Bronchospasm without dynamic hyperinflation	Decreased	Unchanged
Bronchospasm with dynamic hyperinflation	Decreased	Decreased
Atelectasis	Decreased	Decreased
Pneumonia	Decreased	Decreased
Pneumothorax	Decreased	Decreased
Tube obstruction	Decreased	Unchanged
Pulmonary embolism	Unchanged	Unchanged

Troubleshooting Ventilator Alarms



High Pressure



Low Pressure



Low Volume



High Frequency



Apnea



High PEEP



Low PEEP

LOW-PRESSURE ALARM

1. Check for patient disconnection.
2. Check for leaks in the patient circuit related to the artificial airway and through chest tubes.
3. Confirm that the proximal pressure line is connected and unobstructed.
4. Low-pressure alarm may be accompanied by a low minute ventilation or low tidal volume (VT) alarm.



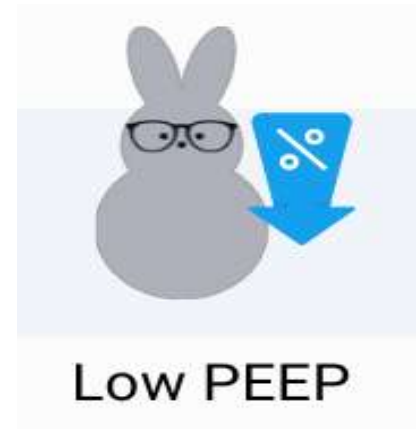
HIGH-PRESSURE ALARM

1. Check whether Raw has increased or CL has decreased
2. Coughing, check for secretions or the patient is biting the ETT
3. Kinking or displacement of the ET; Check ET tube's position
4. Ensure that the main inspiratory or expiratory lines are not kinked or obstructed.
5. Check that the patient is breathing synchronously with the ventilator.
6. Determine whether air trapping (auto-PEEP) has developed.
7. Ensure that the expiratory filter and expiratory valve are functioning properly.



LOW POSITIVE END-EXPIRATORY OR PEEP/CPAP ALARMS

1. Check the low-PEEP alarm is set below the applied PEEP level.
2. Determine whether patient is actively inspiring below baseline.
3. Determine whether a leak is present.
4. Confirm that the patient has not become disconnected from the ventilator.
5. Ensure that the proximal airway pressure (Paw) line is not occluded.



APNEA ALARM

1. Determine whether the patient is apneic.
2. Check for leaks.
3. Check the sensitivity setting to be sure the ventilator can detect patient effort.
4. Check the alarm-time interval and the volume setting, when appropriate.



Auto-PEEP

Additional pressure above the set PEEP
Due to Air trapping

Physiologic mechanisms of auto-positive end-expiratory pressure

Dynamic hyperinflation plus intrinsic expiratory flow limitation
Chronic obstructive pulmonary disease

Dynamic hyperinflation without intrinsic expiratory flow limitation

Breathing pattern and ventilator settings

Rapid breaths

High tidal volume

Inspiration greater than expiration

End-inspiratory pause

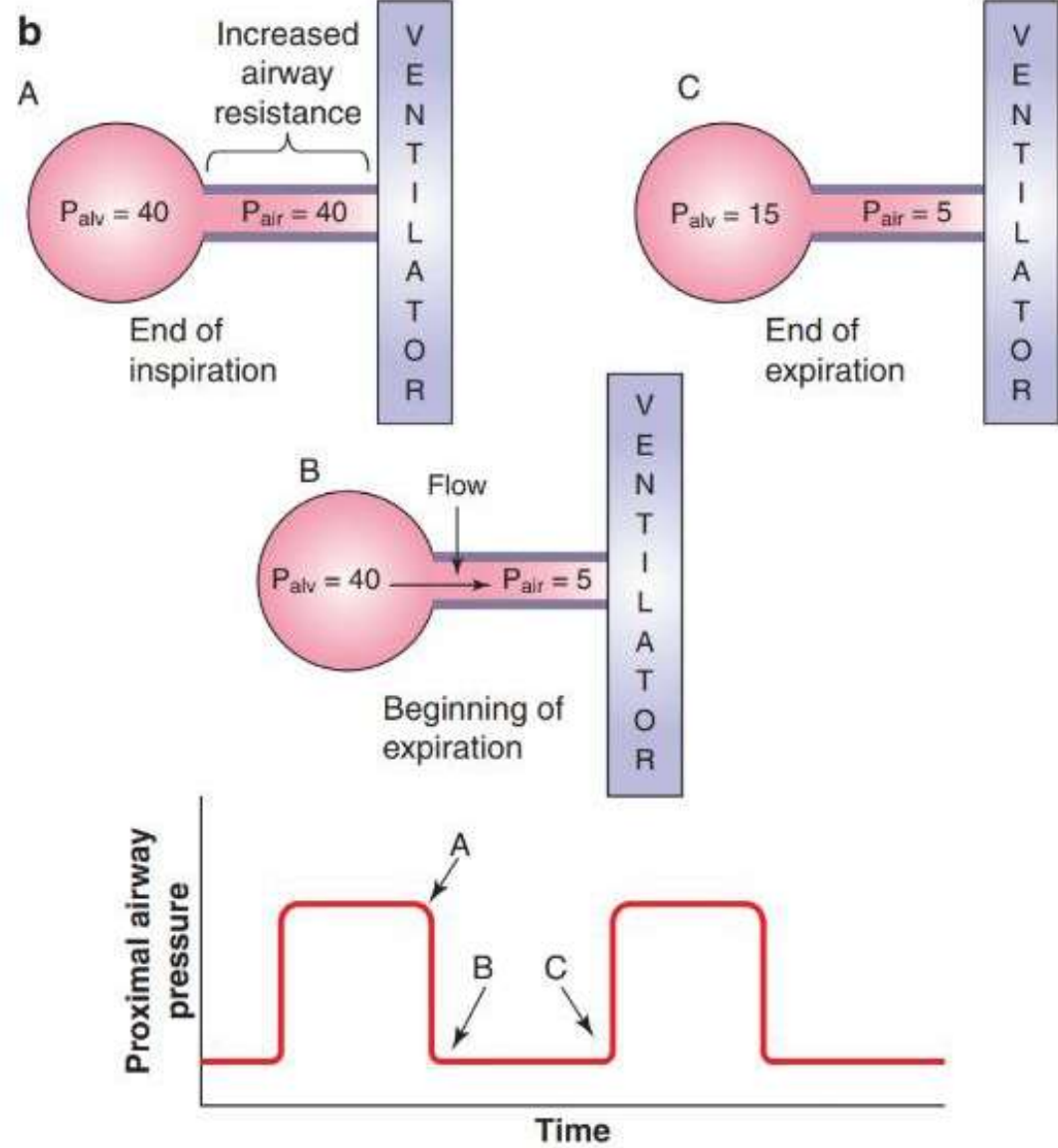
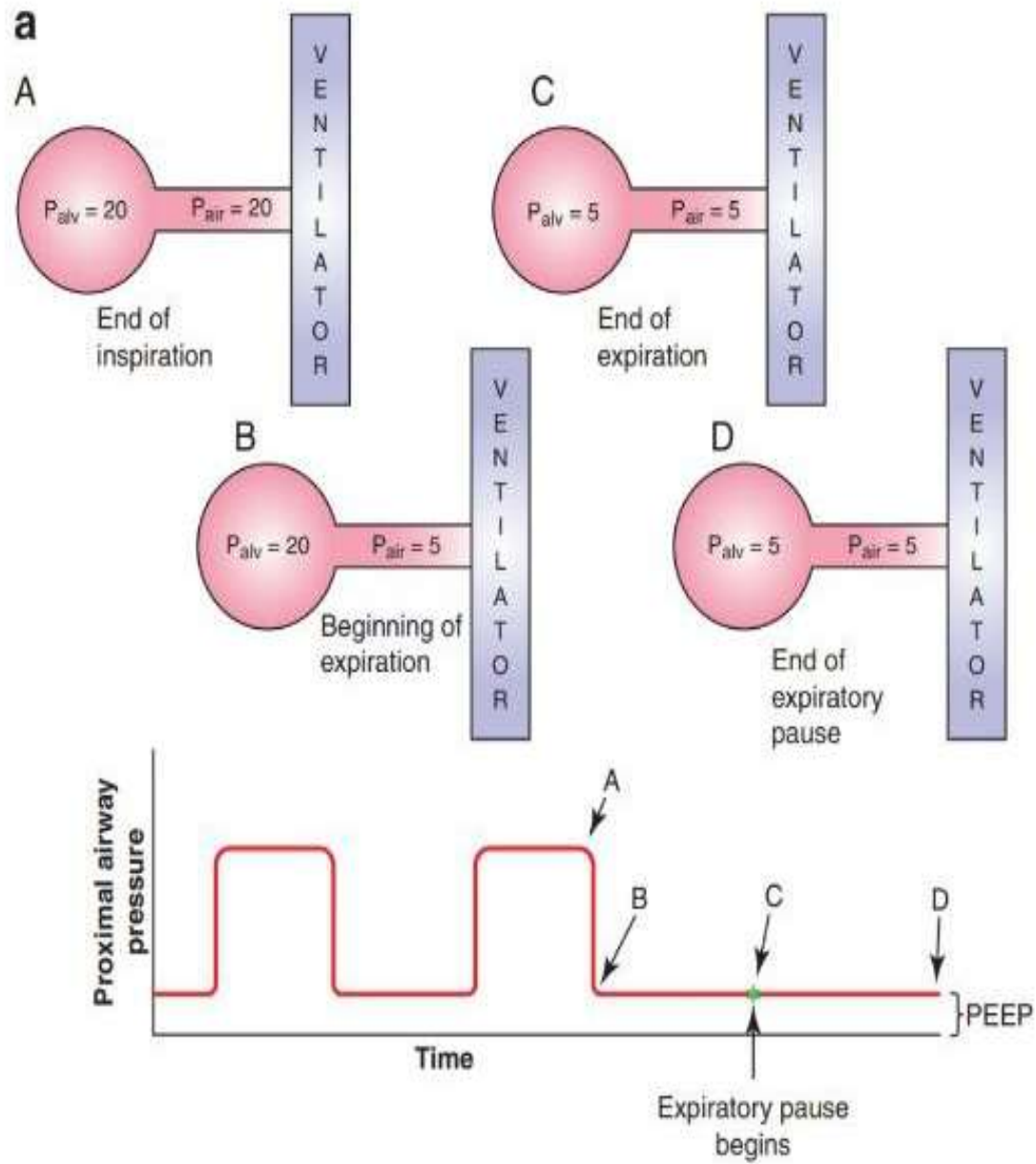
Added flow resistance

Fine-bore endotracheal tube

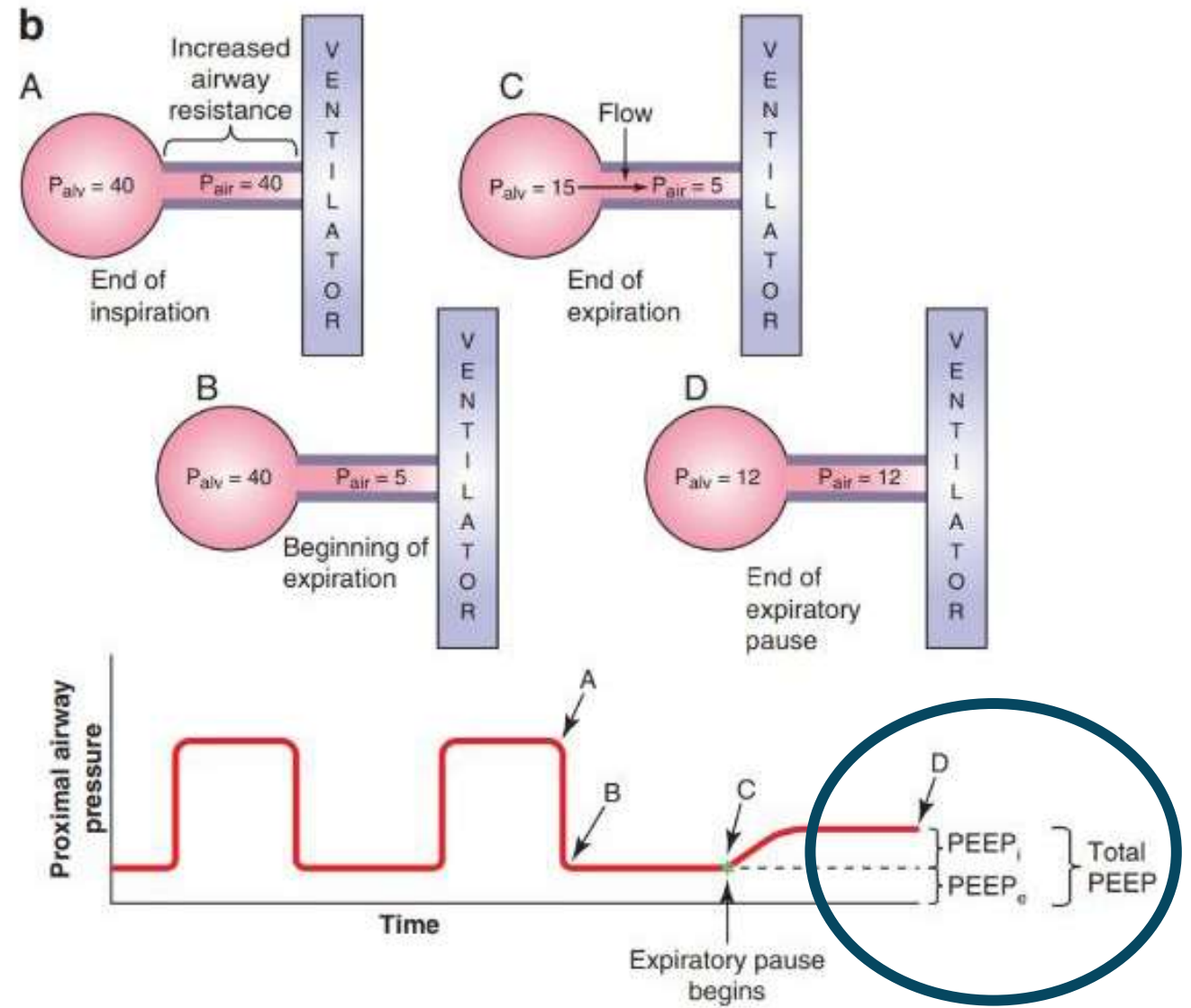
Ventilator tubing and devices

Without dynamic hyperinflation

Recruitment of expiratory muscles



EXPIRATORY HOLD



Low SpO2



2025-09-22 01:28:52

INTELLiVENT

(S)CMV

Adult/Ped.

Patient

Additions

Modes

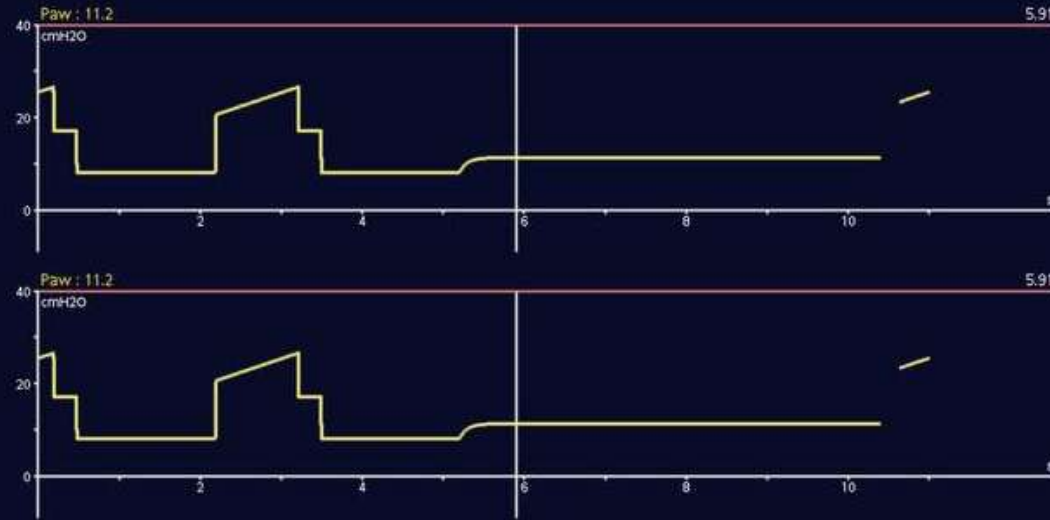
40
5
23 Ppeak
cmH2O

9.5
4.0
8.6 ExpMinVol
l/min

800
270
430 VTE
ml

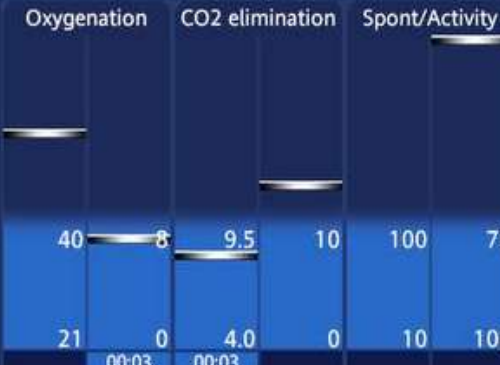
40
0
20 fTotal
b/min

1.71 RCexp
s



90 **83 %SpO2**

Adult Male
170 cm
IBW = 66 kg



Rinsp	Cstat	PetCO2	SpO2	Pulse	HLI
22	73	55	83	112	0
cmH2O/l/s	ml/cmH2O	mmHg	%	l/min	%

Oxygen	PEEP	MinVol	Pinsp	RSB	%fSpont
60	8	9	15	---	0
%	cmH2O	l/min	cmH2O	l/(l*min)	%

20
b/min

Rate

430
ml

Vt

8
cmH2O

PEEP/CPAP

60
%

Oxygen

Controls

Alarms

Monitoring

Graphics

Tools

Events

System

Treatment of auto-positive end-expiratory pressure

Change ventilator settings

- Increase expiratory time
- Decrease respiratory rate
- Decrease tidal volume

Reduce ventilatory demand

- Reduce anxiety, pain, fever, shivering
- Reduce dead space
- Give sedatives and paralytics

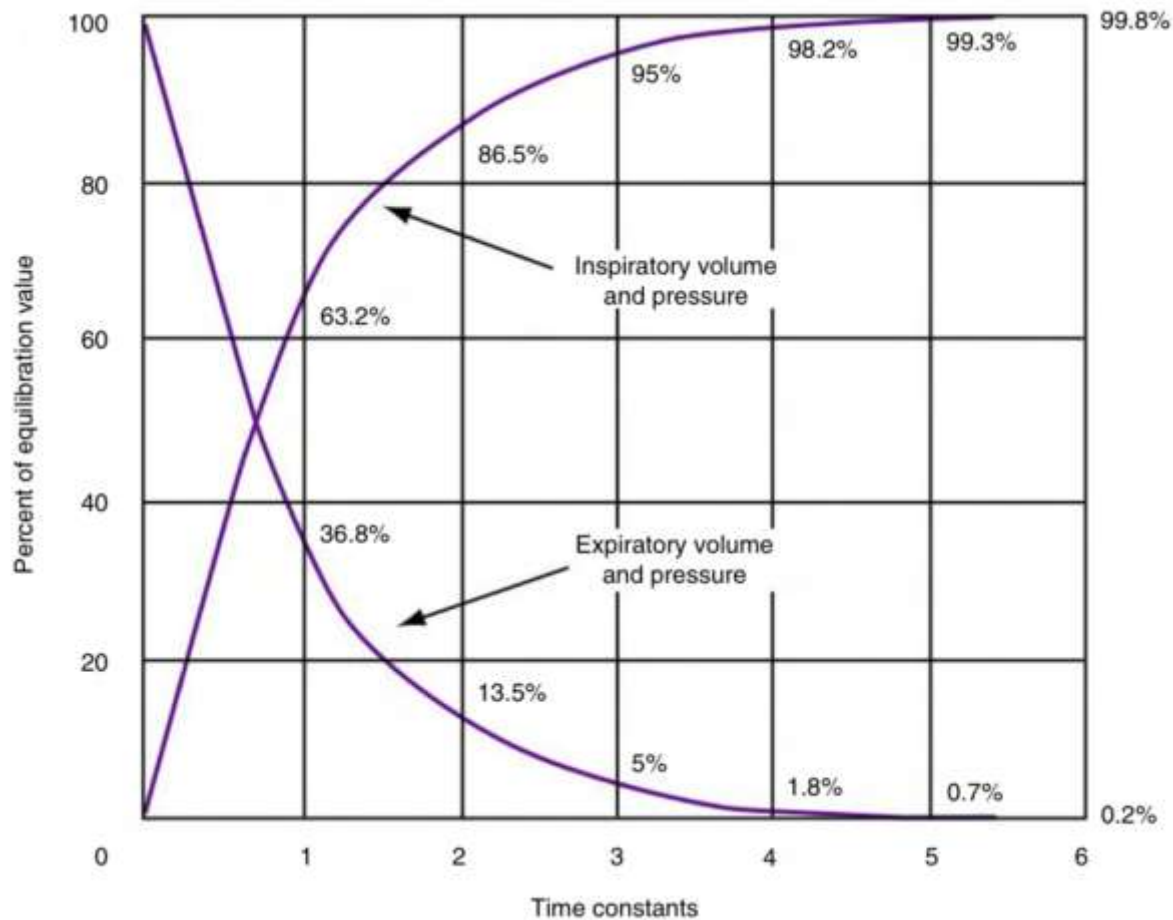
Reduce flow resistance

- Use large-bore endotracheal tube
- Suction frequently
- Give bronchodilators

Counterbalance expiratory flow limitation

- External positive end-expiratory pressure

Respiratory Time Constant (RC)



Product of Compliance (C) and Resistance(Raw)
 $RC = C \text{ (L/cm H}_2\text{O)} \times R_{aw} \text{ (cm H}_2\text{O}/(\text{L}/\text{sec}))$

Equals the length of time (in seconds)required for the lungs to inflate or deflate to a certain amount(percentage) of their volume.

-
- Theoretical model based upon the simple premise of a constant pressure generator connected to a single compartment with fixed resistance and a compliance component.
 - Describes passive pressure control ventilation, whereby a fixed airway pressure produces an exponential curve for changes in flow, and volume changes between the proximal airway and the alveoli
 - R_{cinsp} (Inspiratory time constant) - Essentially influenced by ventilator settings during the inspiratory phase
 - R_{CEXP} (Expiratory time constant) - Result of passive elastic recoil of the lung and the chest wall.

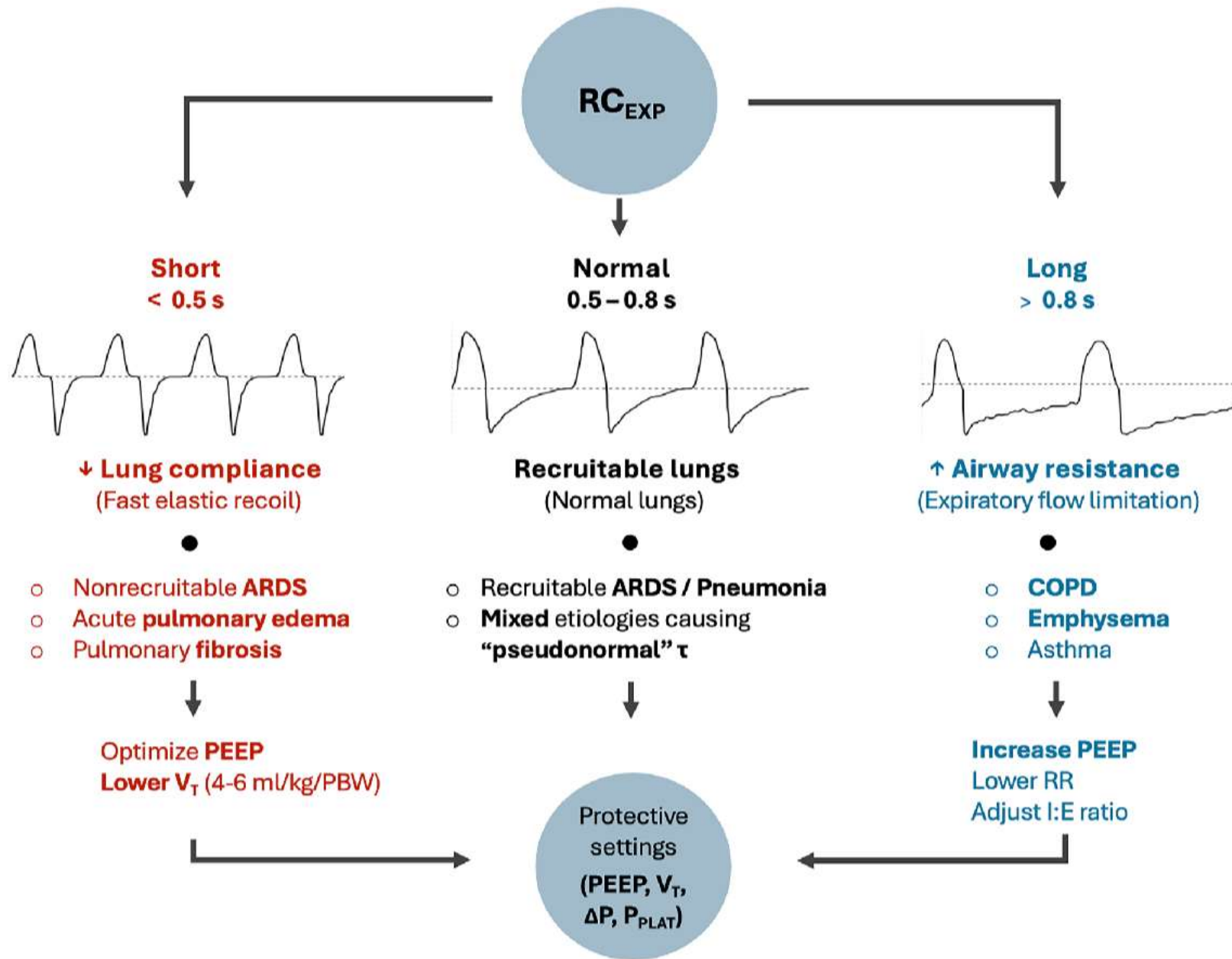
Reference Values

Table 1 Typical range of time constants in passive intubated patients with various disease states

Short $RC_{EXP} < 0.5 \text{ s}$	Normal $RC_{EXP} 0.5\text{--}0.8 \text{ s}$	Long $RC_{EXP} > 0.8 \text{ s}$
Nonrecruitable (stiff) ARDS	Normal lungs	COPD
Fibrosis	Recruitable lungs	Asthma
Acute pulmonary edema	Mixed conditions*	Emphysema
Kyphoscoliosis		Chronic bronchitis
Chest wall stiffness		Bronchospasm

* Coexisting (mixed) pathologies can have pseudo-normal RC_{EXP} due to various combinations of R_{RS} and C_{RS} . ARDS—acute respiratory distress syndrome, COPD chronic obstructive pulmonary disease, RC_{EXP} expiratory time constant

Depta et al. Intensive Care Medicine Experimental (2025) 13:40



ASV MODE AND GRAPH

ASV

Launched: In 1998

*Standard V_T in ICU: 9 (8–10) ml/kg IBW

Based on: **Otis' formula**
Minimum work of breathing

ASV 1.1

Launched: In 2016

**Standard V_T in ICU: 7.5 ml/kg IBW

Based on: **Otis' formula**
Minimum work of breathing
Mead's formula
Minimum force of breathing

*

**

ASV MODE AND GRAPH

Breathing pattern

Otis' formula^{*}

Minimum work of breathing

Mead's formula^{**}

Minimum force of breathing



Two elements in common: RC_{exp} and V_A/V_D

Target respiratory rate

Otis' formula

Minimum work of breathing*

$$f_w = \frac{\sqrt{1 + 4\pi^2 RC \dot{V}_A/V_D} - 1}{2\pi^2 RC}$$

f_w – Minimum work frequency

RC – Time constant

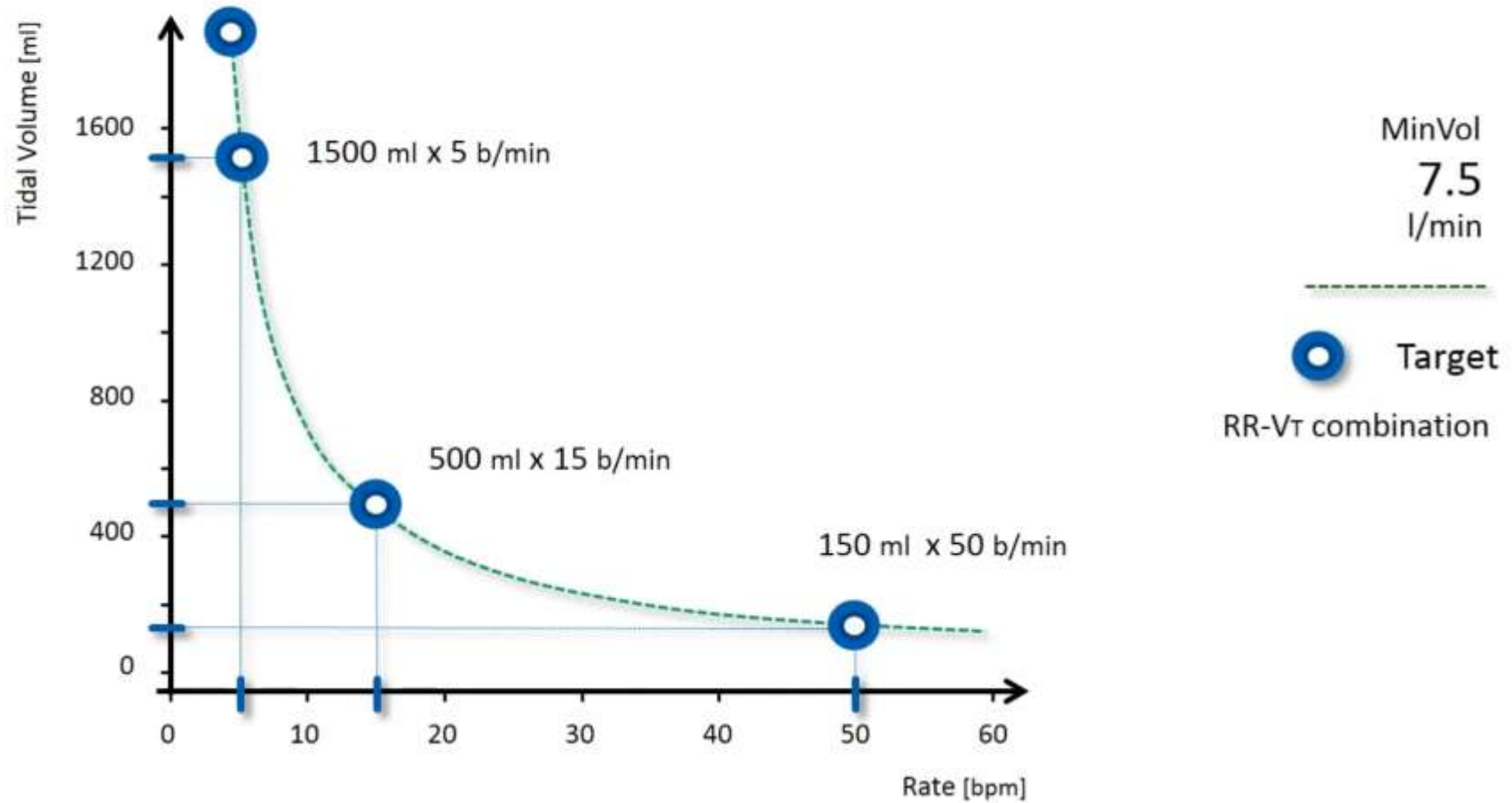
V_A – Alveolar ventilation

V_D – Dead space ventilation

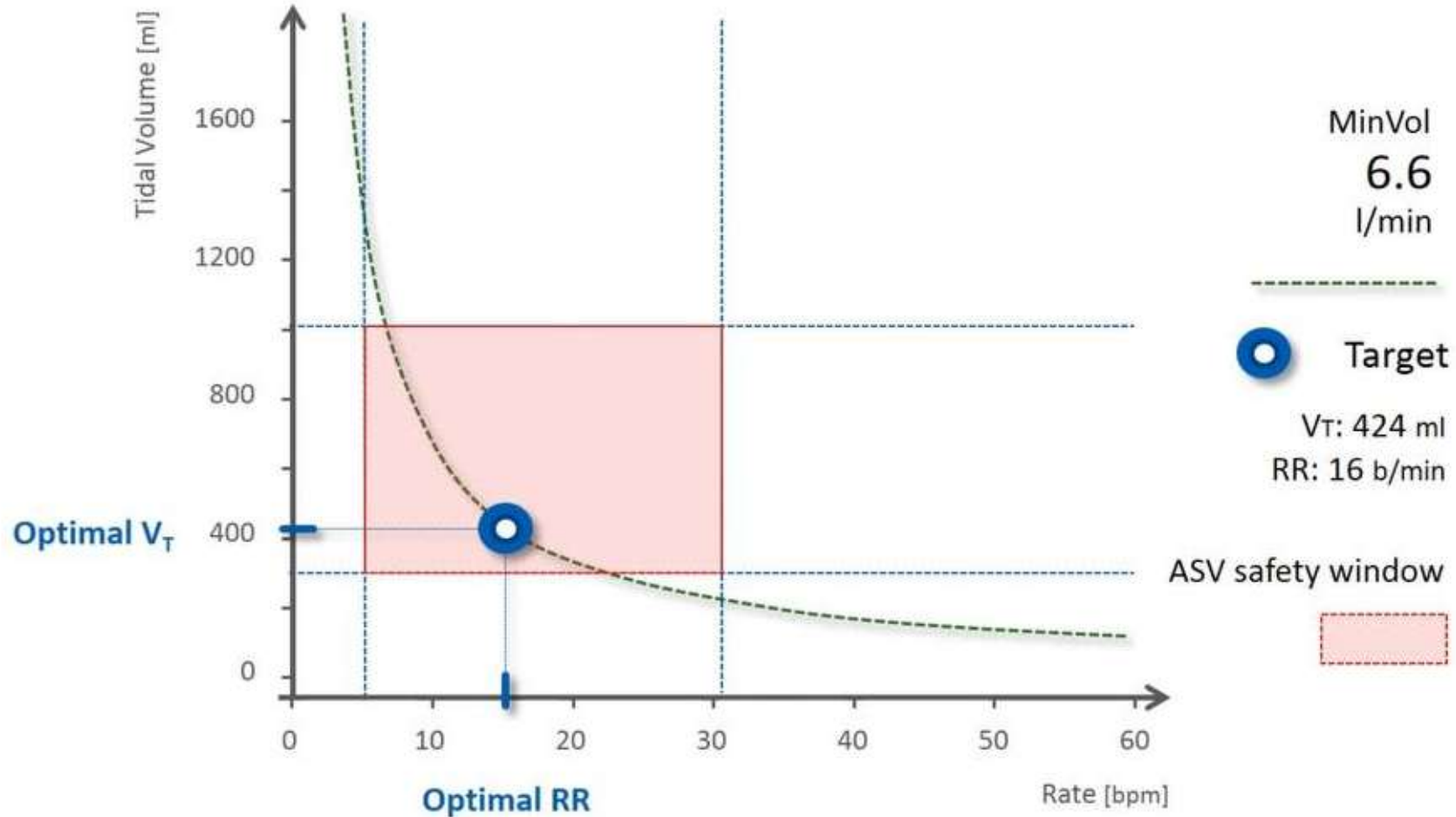
*Otis AB, et al. Mechanics of Breathing in Man. J App Physiol 1950; 2:592-607

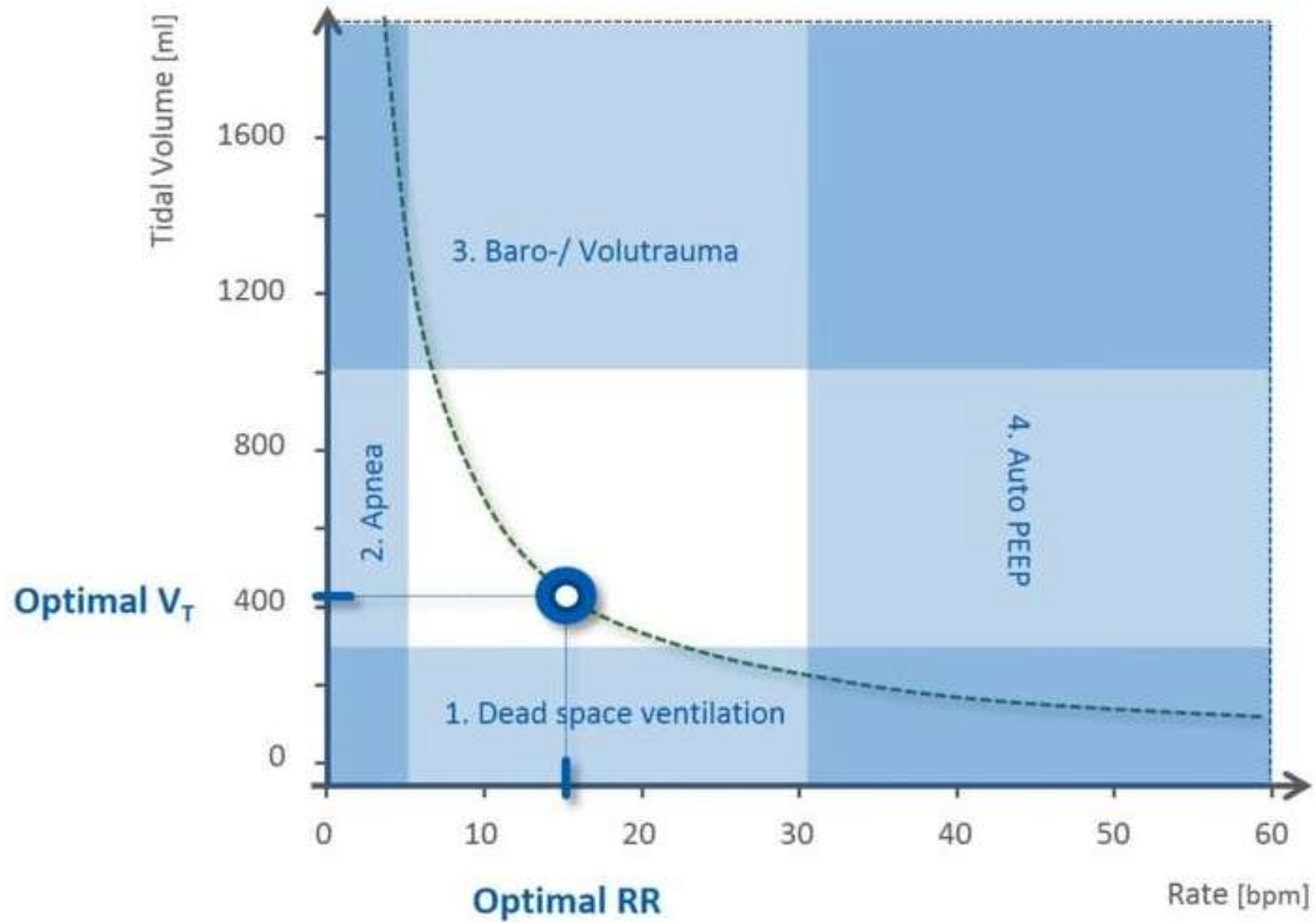
Mead J. Control of respiratory frequency. J Appl Physiol 15(3) : 325-336

Minute Ventilation

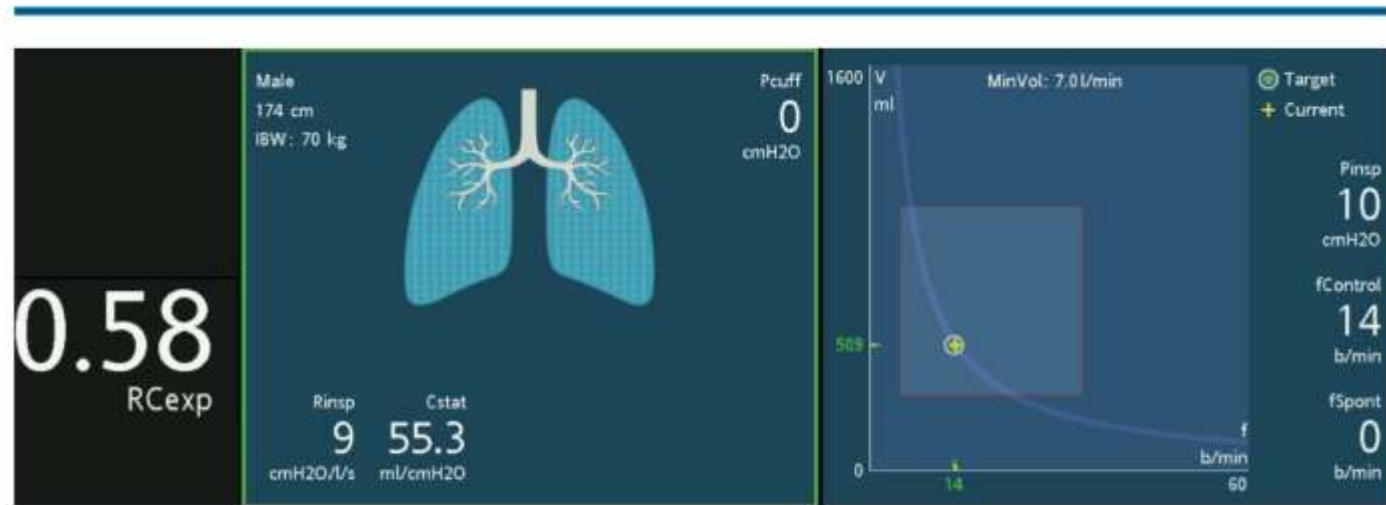


Safety Window





Normal lungs



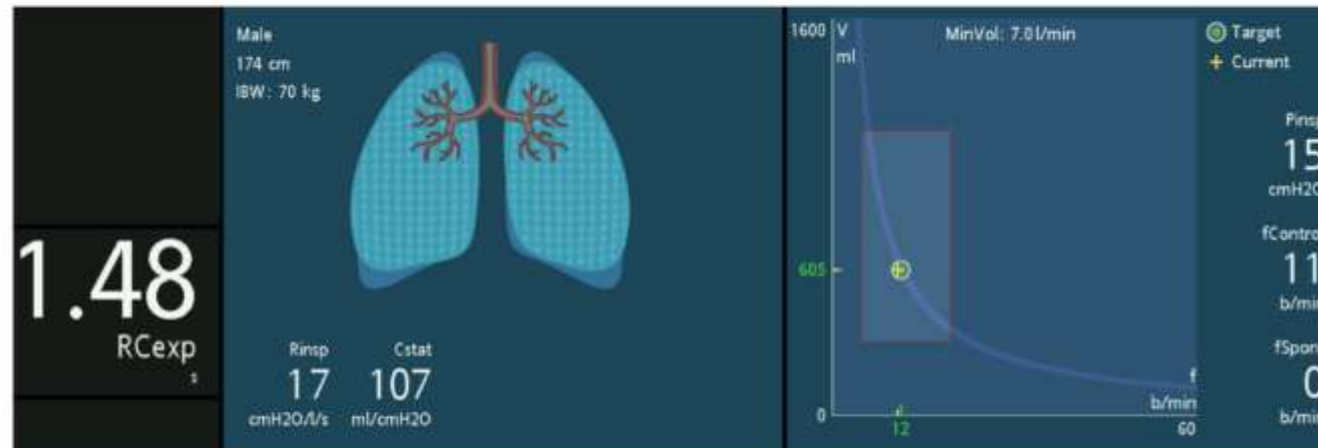
R_{Cexp} (s)	R_{insp} (cmH ₂ O s/l)	C_{stat} (ml/cmH ₂ O)
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0.50 – 0.70	10 – 15	45 – 65
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Wide square-shaped safety window

Obstructive lung diseases

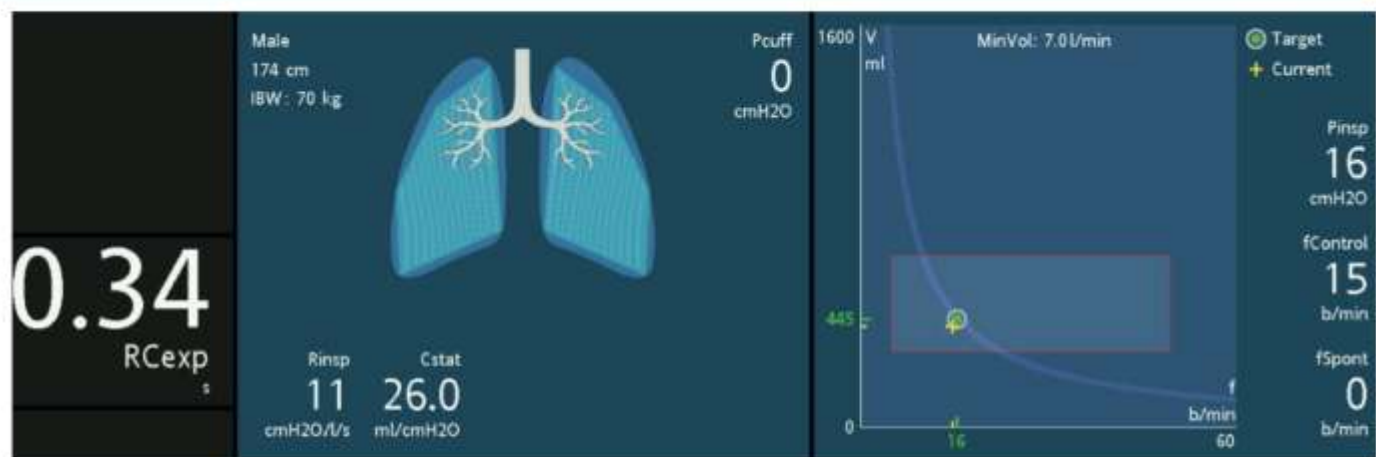


RCexp (s)	Rinsp (cmH2O s/l)	Cstat (ml/cmH2O)
> 0.70*	16 – 33	50 – 80

* A long RCexp (> 0.70 s) indicates increased resistance due to the patient and/or the endo-tracheal tube: COPD, asthma, bronchospasm, endotracheal tube obstruction, and the like.¹

Narrow and high safety window

Restrictive lung diseases



RC_{exp} (s)	R_{insp} (cmH ₂ O s/l)	C_{stat} (ml/cmH ₂ O)
< 0.50*	10 – 15	< 45

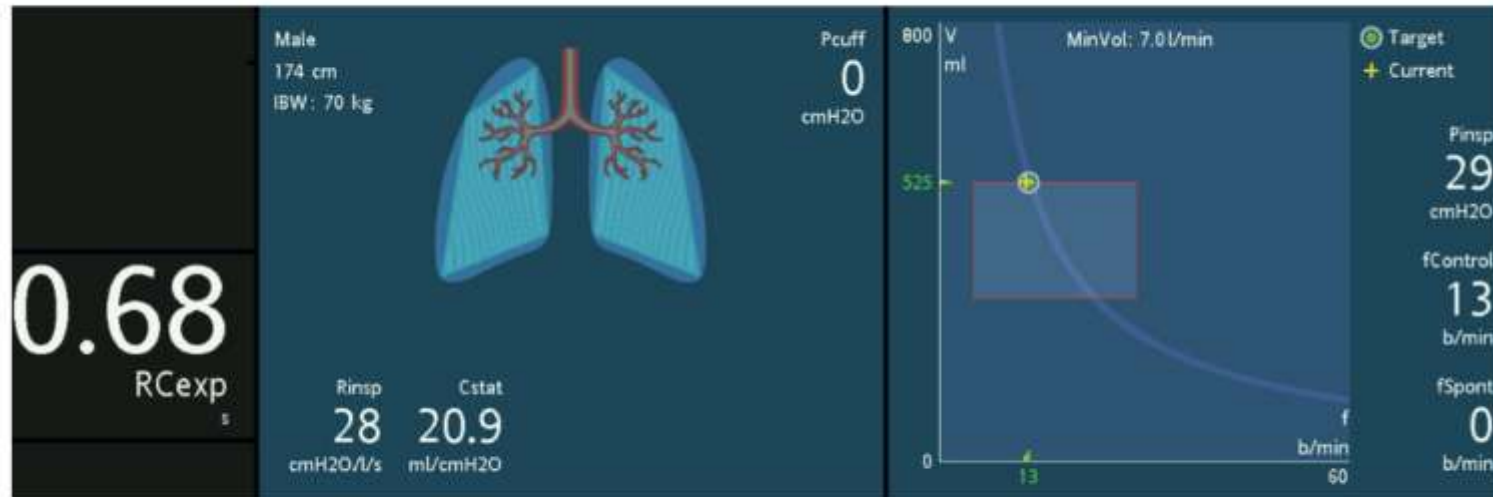


Low and wide safety window
(low compliance = stiff lung)

*A short RC_{exp} (< 0.50 s) indicates decreased compliance due to the lung and/or the chest wall: ARDS, lung fibrosis, atelectasis, kyphoscoliosis, increased abdominal pressure, and the like.¹

Volume

Mixed conditions

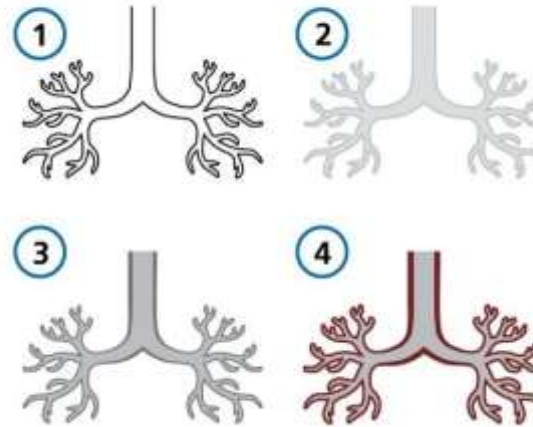


RCexp (s)	Rinsp (cmH2O/l/s)	Cstat (ml/cmH2O)
0.50 – 0.70	> 16	< 45



Narrow rectangular safety window

Airway Resistance Graphic



1 Resistance information is unavailable

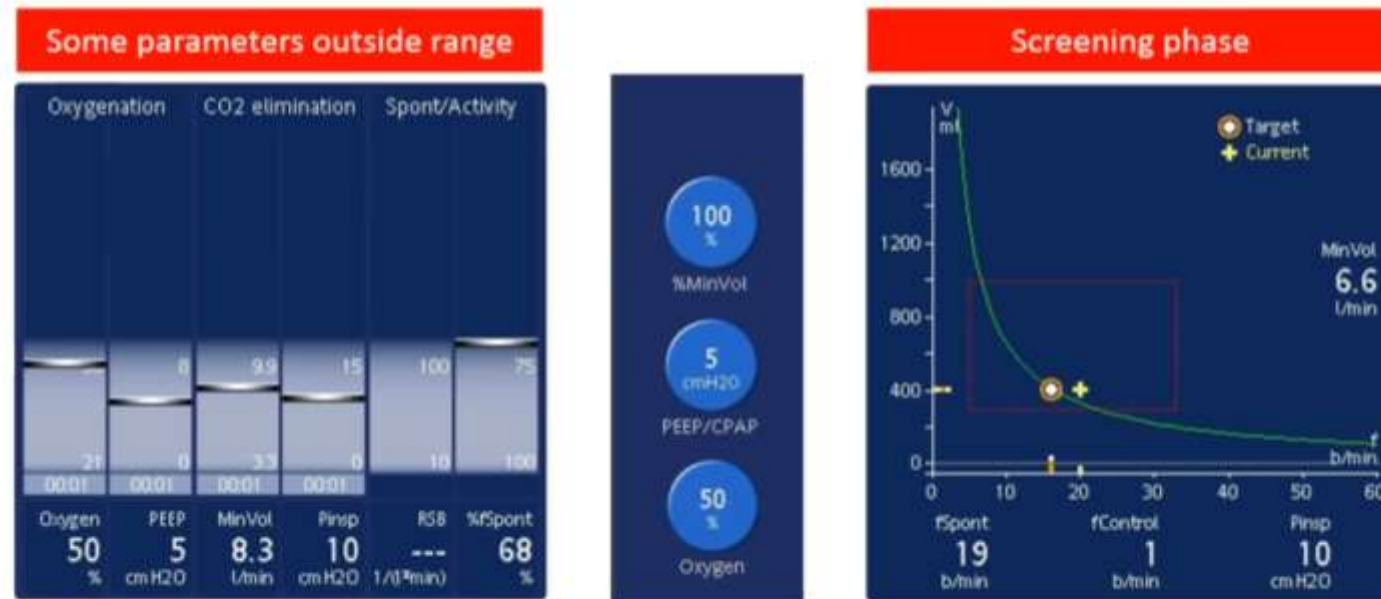
2 Normal resistance

3 Moderate resistance

4 High resistance

Ventilator Cockpit

Vent Status: Readiness-to-wean criteria



LOOPS

- P-V Loop
- F-V Loop
- Quasi-Static Loop

LOOPS

Relationship between two respiratory variables plotted on X and Y axis

Each loop consists of an inspiratory and an expiratory curve

Both curves graphed together form a distinctive “loop” shape

Primary types of loop graphics are:

Pressure-volume (P-V) Loop

Flow-volume (F-V) Loop

LOOPS

Relationship between two respiratory variables plotted on X and Y axis

Each loop consists of an inspiratory and an expiratory curve

Both curves graphed together form a distinctive “loop” shape

Primary types of loop graphics are:

Pressure-volume (P-V) Loop

Flow-volume (F-V) Loop

PRESSURE-VOLUME LOOPS

Tracing begins in lower left-hand corner

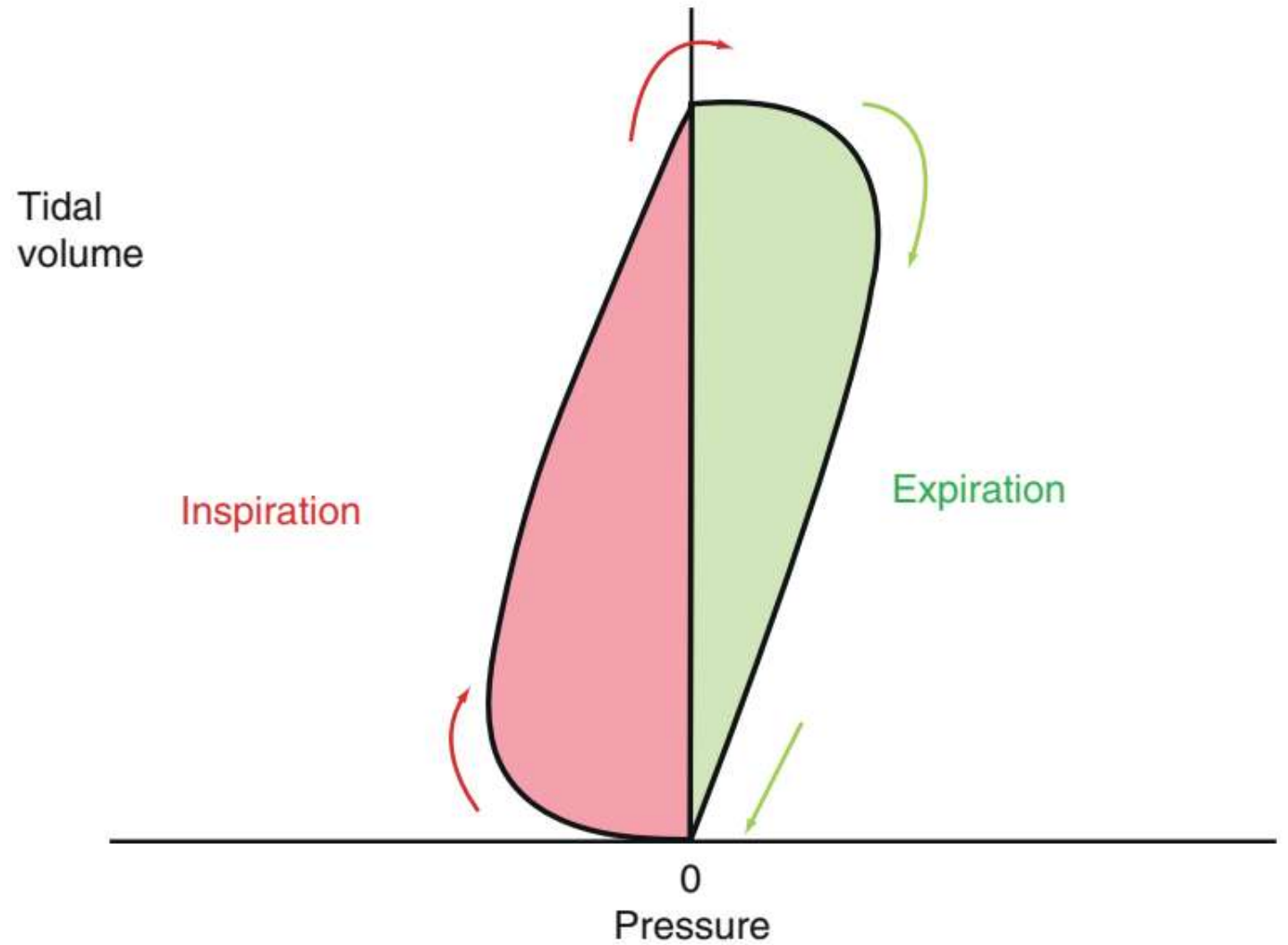
At end expiration, returns to the point of initiation

Tidal Volume - Highest point of PV loop on Y-axis

Peak Pressure - Same point read against the X-axis

Change in volume per unit change in pressure - compliance

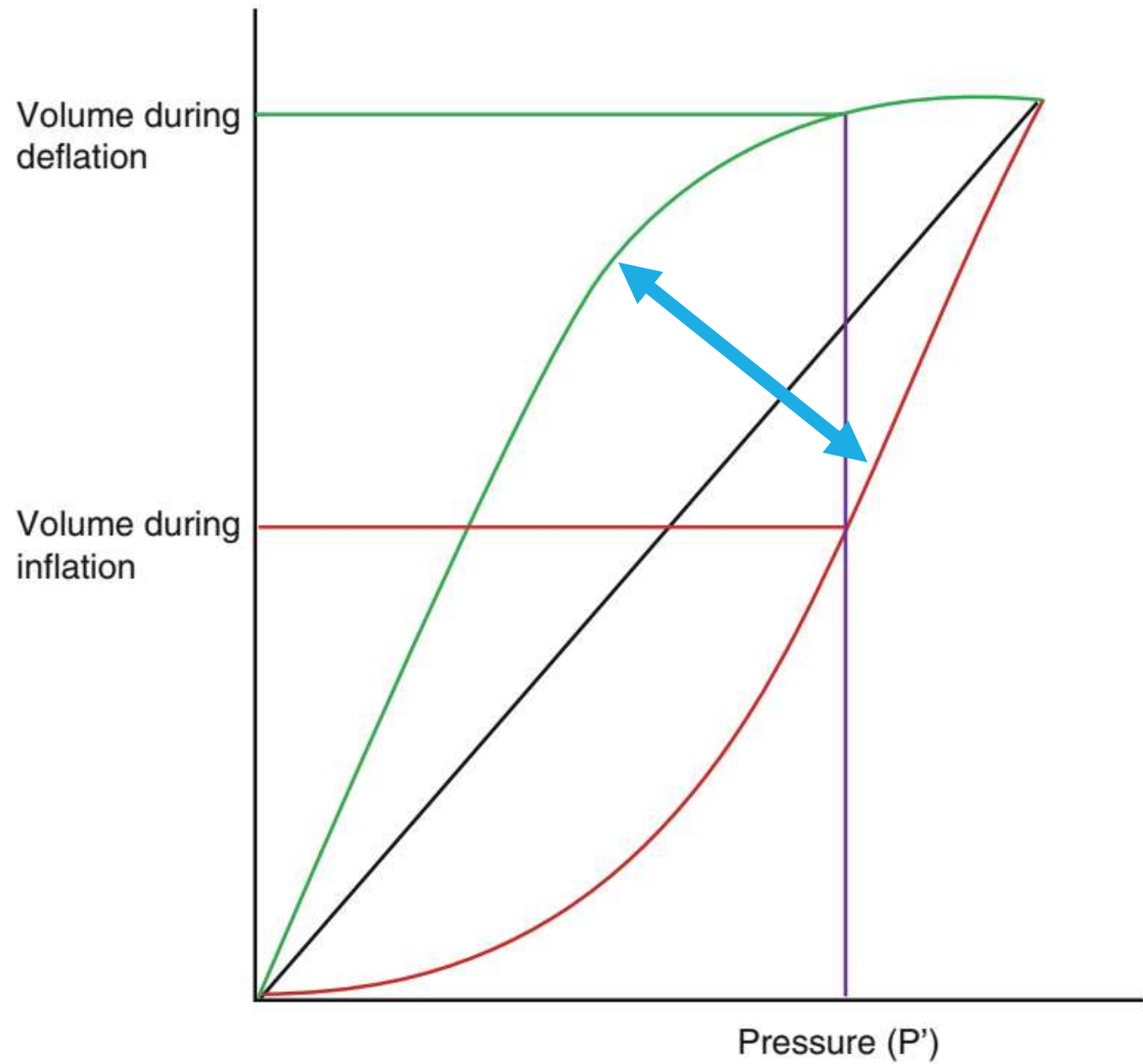
Spontaneous Breath



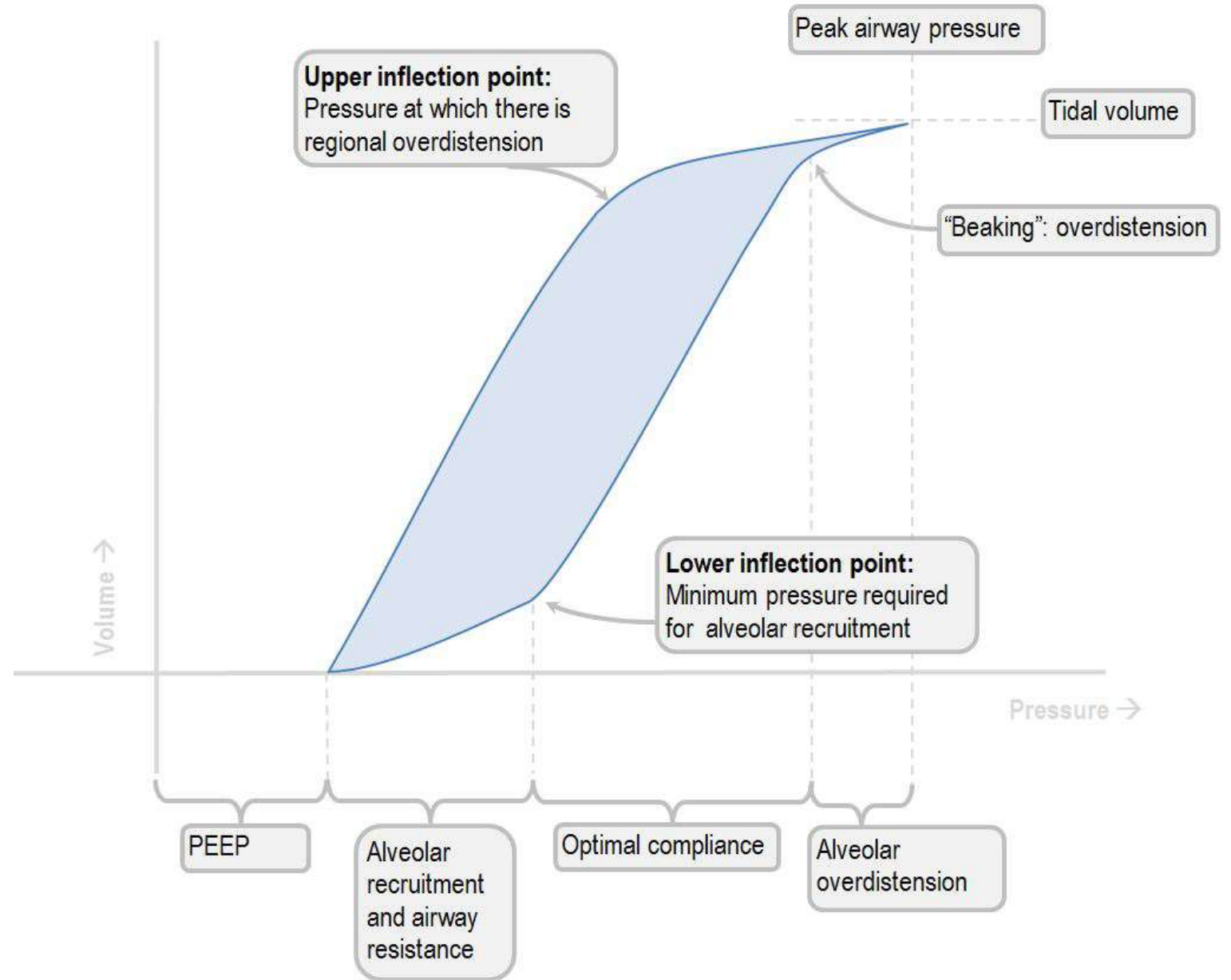
J.M. Cairo. Pilbeam's Mechanical Ventilation. Elsevier, New York, 2024

Mandatory Breath

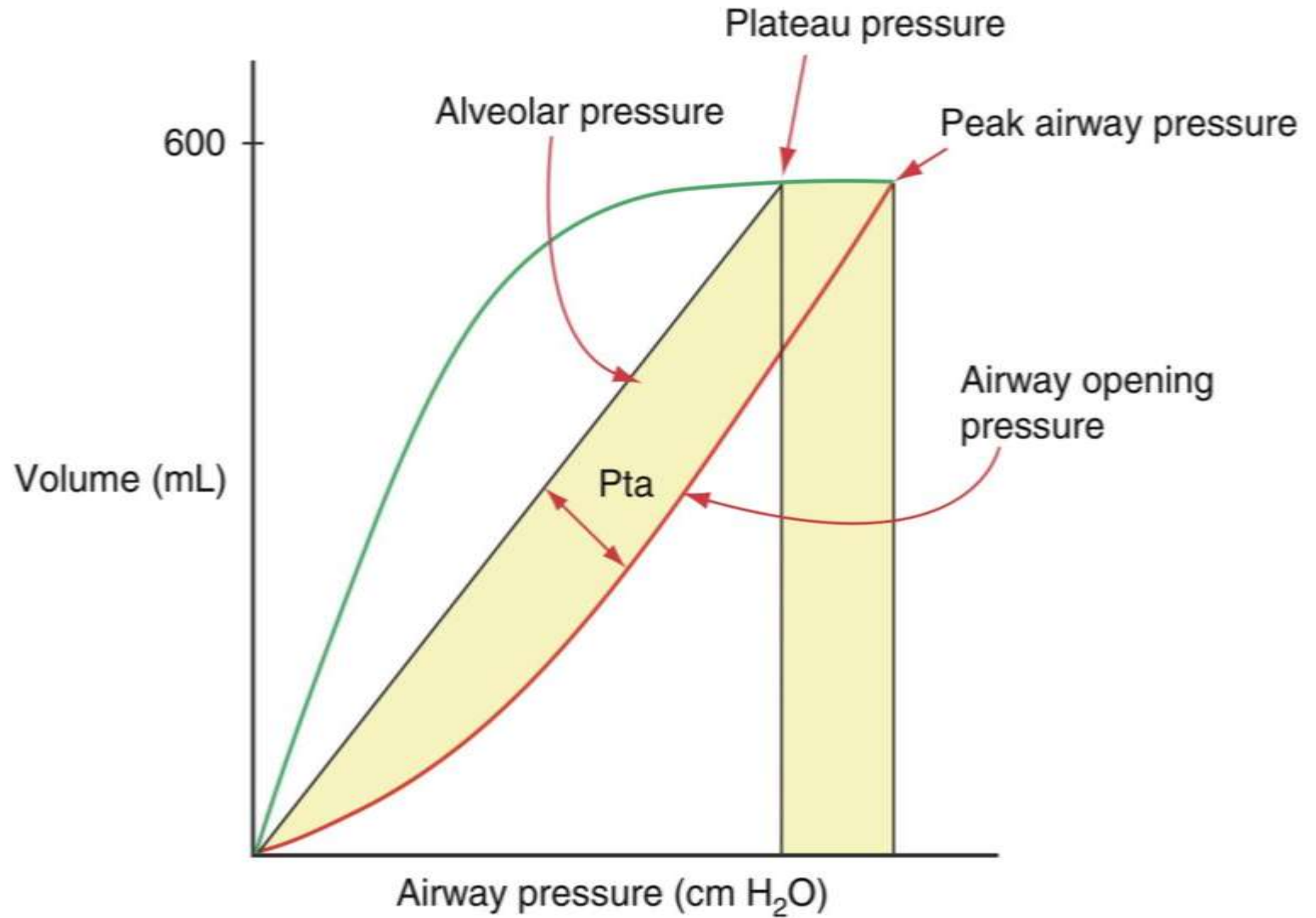
VCV Mode



Controlled Breath VCV Mode

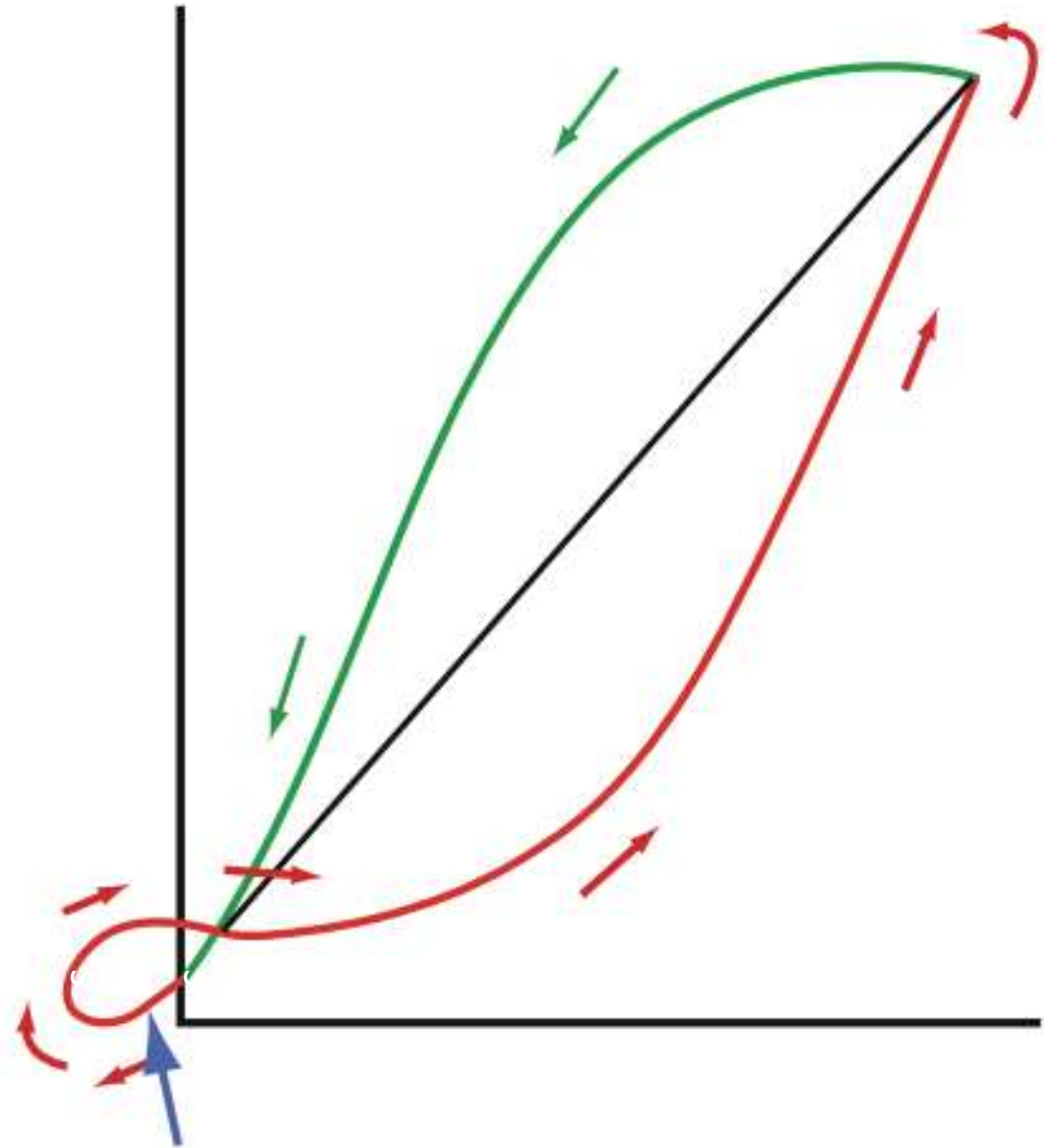
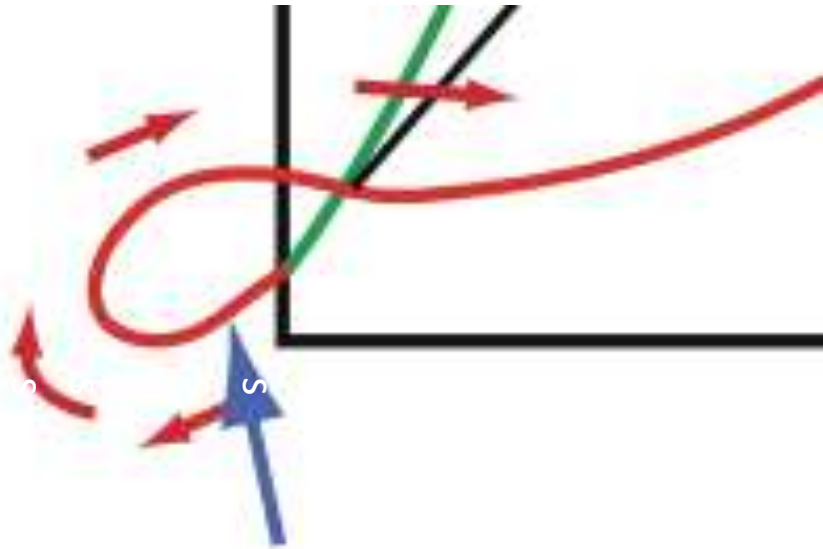


Airway Pressures and P-V Loop

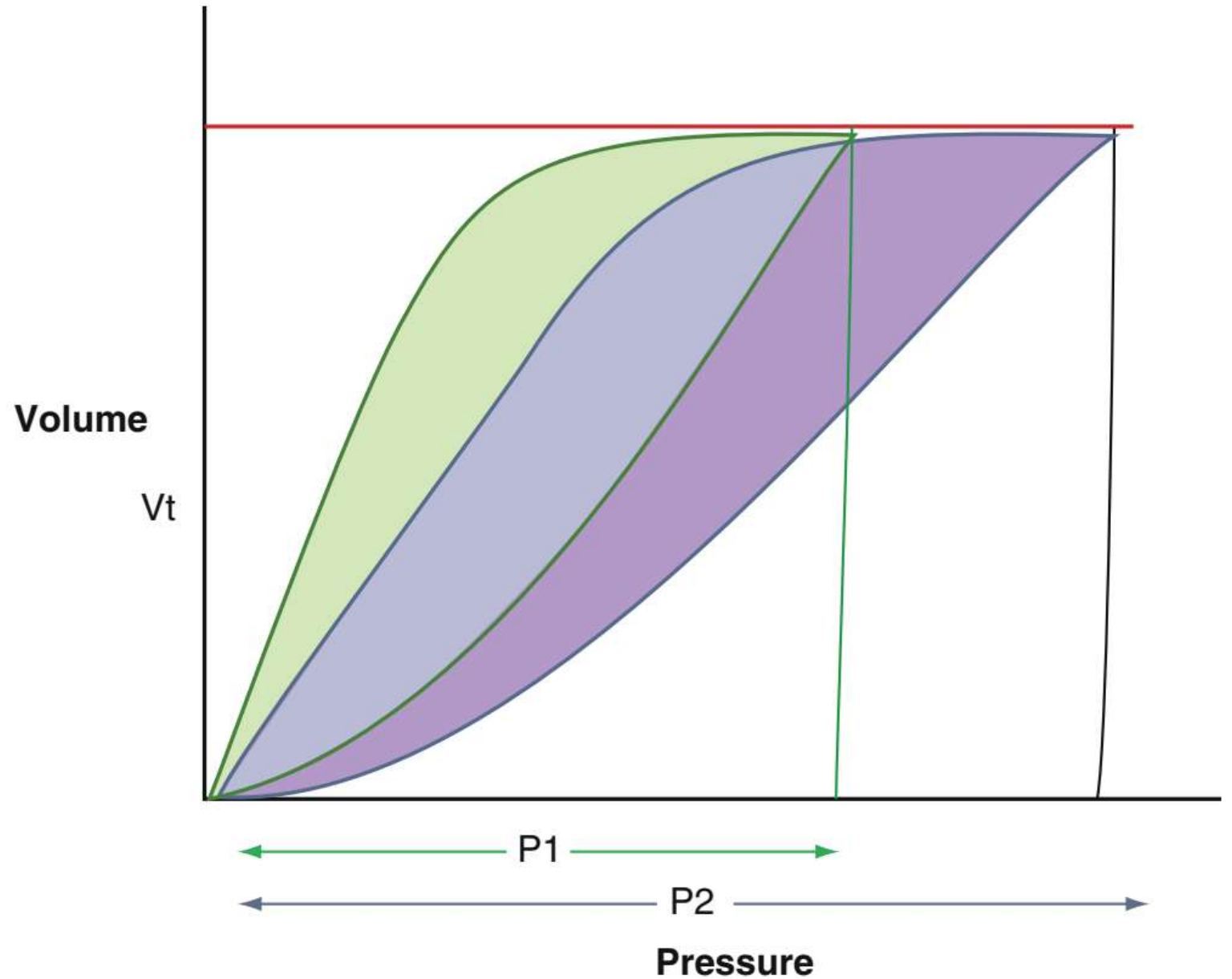


Patient-triggered breath in CMV Mode

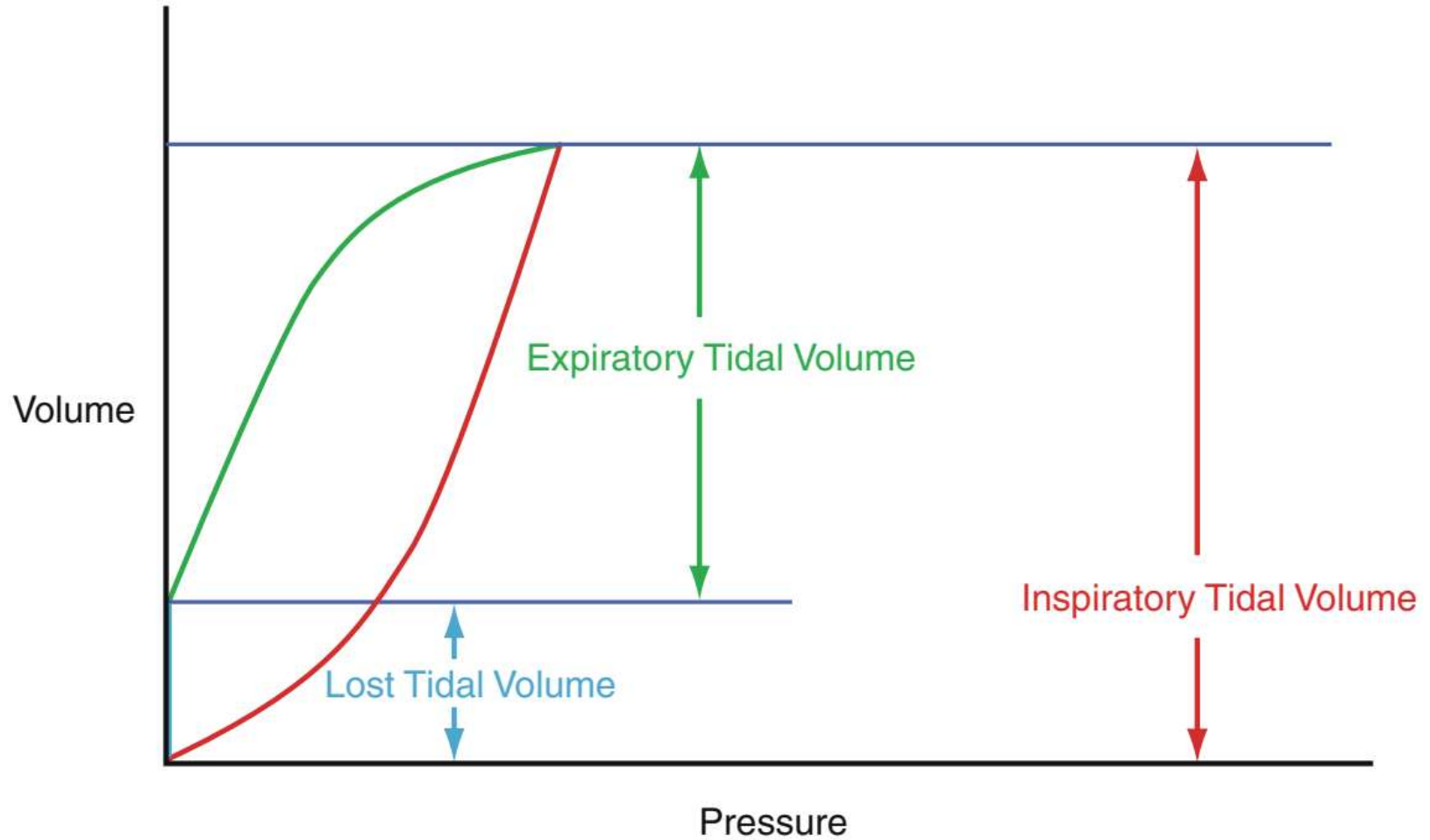
- The drop in airway pressure prior to the positive pressure breath denotes the patient's triggering effort
- Initial Clockwise followed by counter-clockwise movement



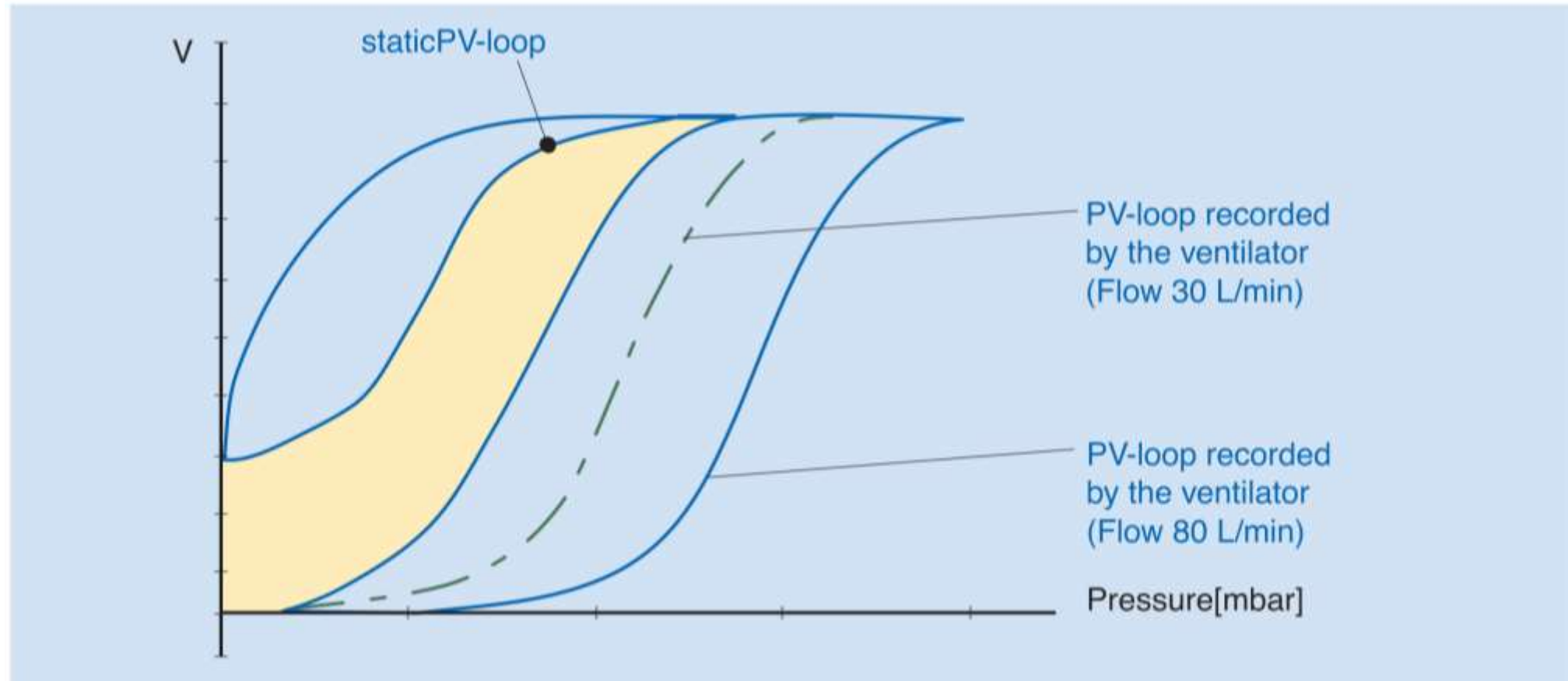
PV Loops in VCV
Mode at Different
Compliances



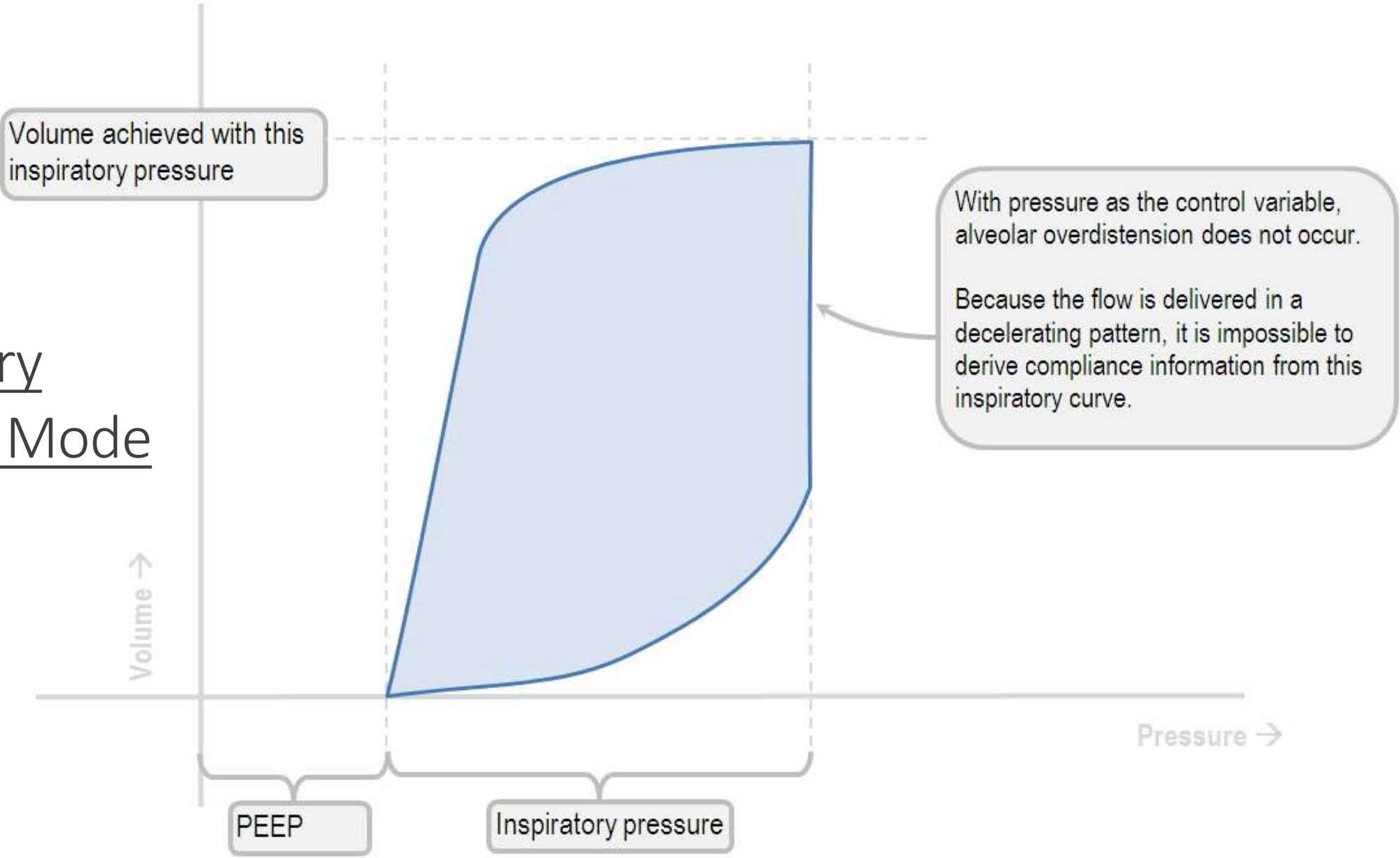
PV Loop with Volume Loss



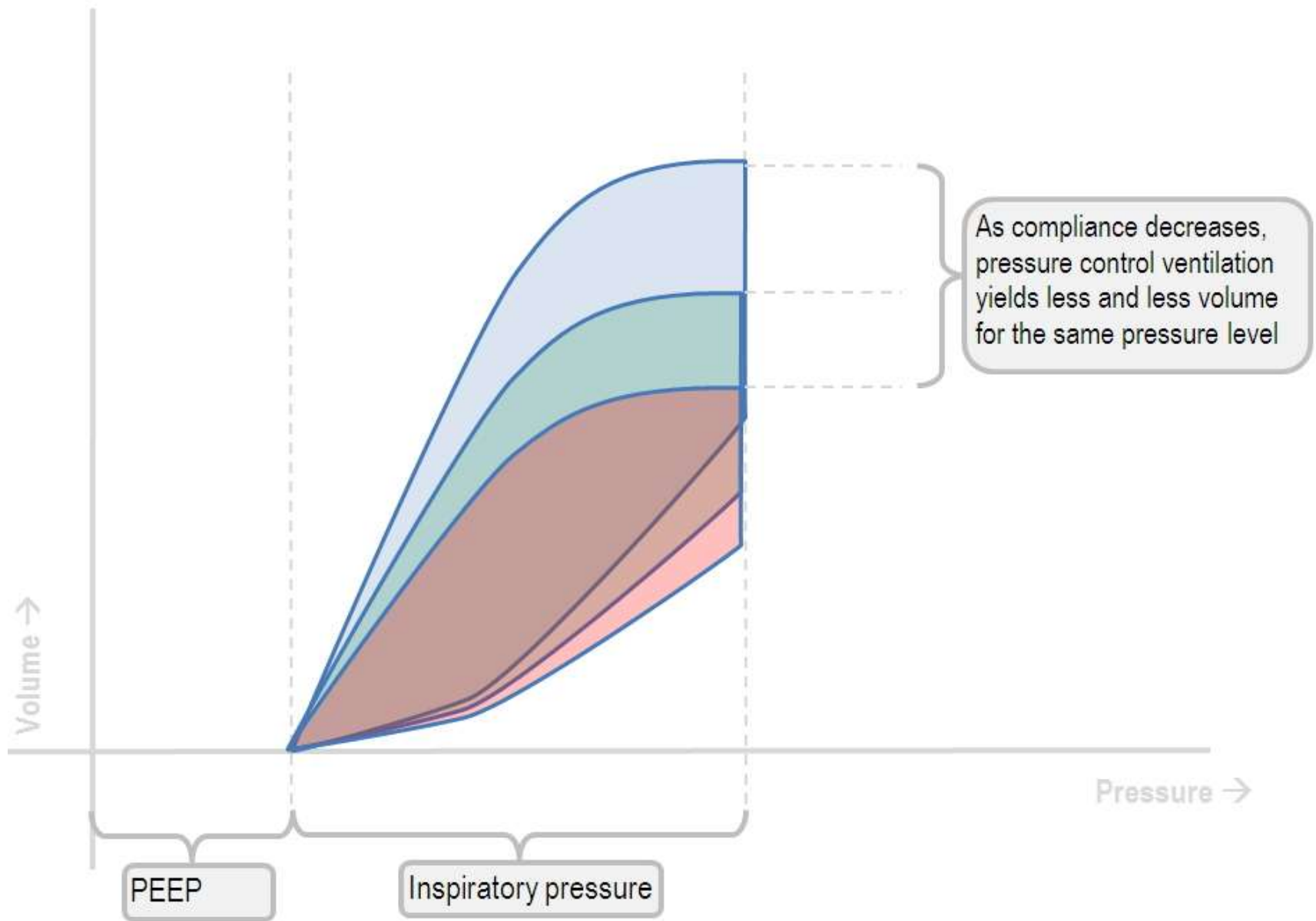
PV Loop and Flow



Mandatory Breath in PCV Mode



PV Loops in PCV Mode at Different Compliances



Quasi-Static Pressure-Volume (PV) Loop

- Diagnostic Maneuver
- With the patient completely passive, either a low constant flow or slow pressure ramp is used to inflate the lungs from 0 up to 40 cm H₂O and then decreased gradually from 40 down to 0 cm H₂O
- The slope of the PV loop at each point of pressure represents the compliance of the respiratory system

Assessing Potential for Recruitment

✓ **High potential for recruitment**

NMD% \geq **41%**

$$\text{NMD\%} = \frac{\text{Max. delta volume (dV) between inflation and deflation}}{\text{Maximum volume}}$$

✗ **Low potential for recruitment**

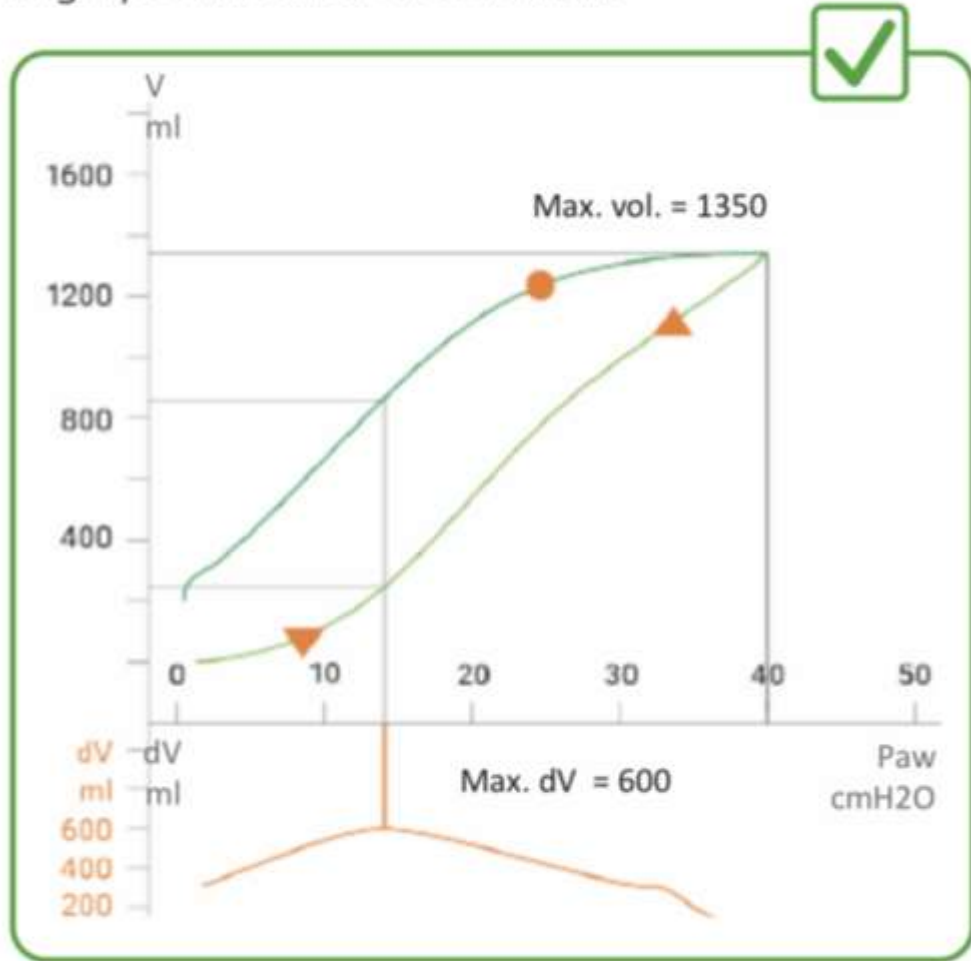
NMD% $<$ **41%**

Consider:

- Keeping PEEP $<$ 10 cmH₂O
- Prone positioning
- Persistent hypoxemia → Consider ECMO

NMD% \geq 41%

High potential for recruitment

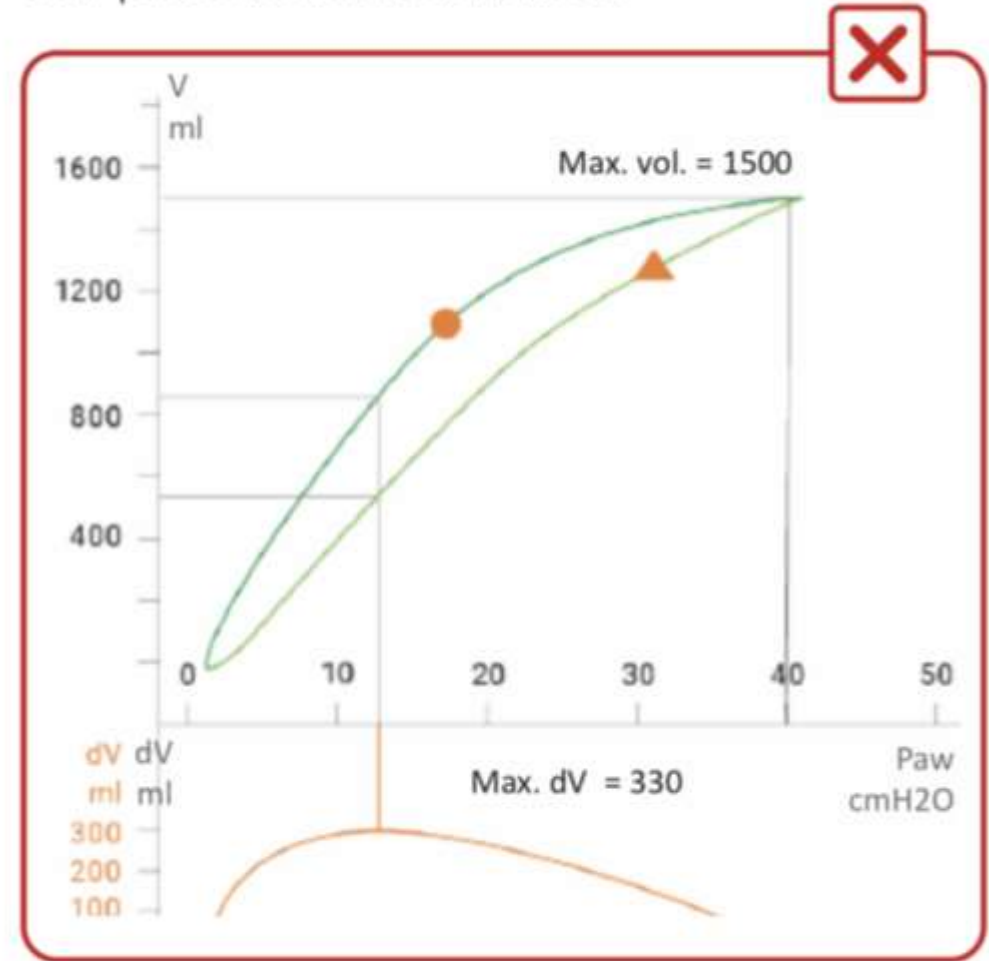


Max. dV / Max. volume = 600/1350

NMD% = 44%

NMD% $<$ 41%

Low potential for recruitment



Max. dV / Max. volume = 330/1500

NMD% = 22%

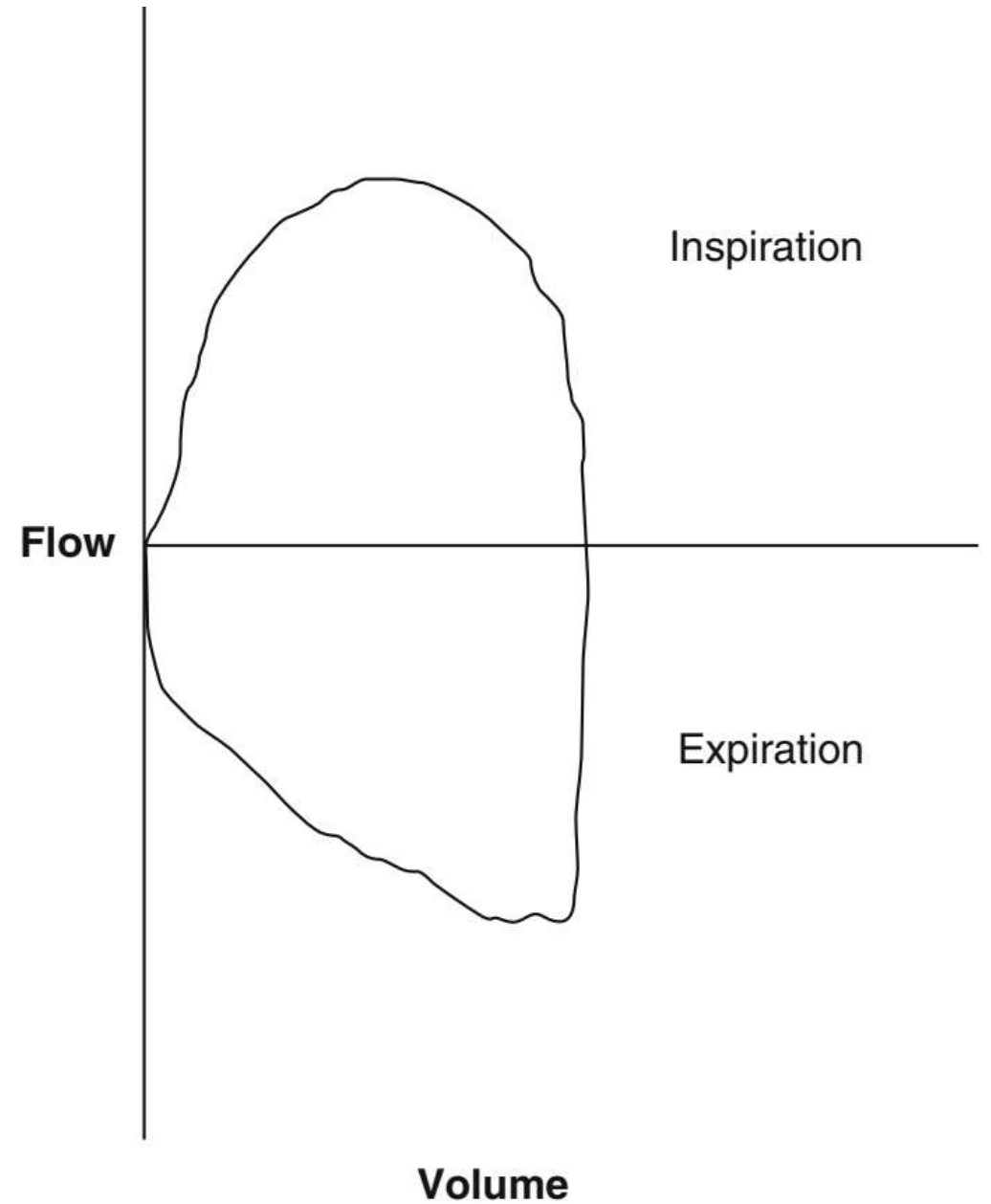
Flow – Volume Loops

Flow (y-axis) is graphed against volume (x-axis)

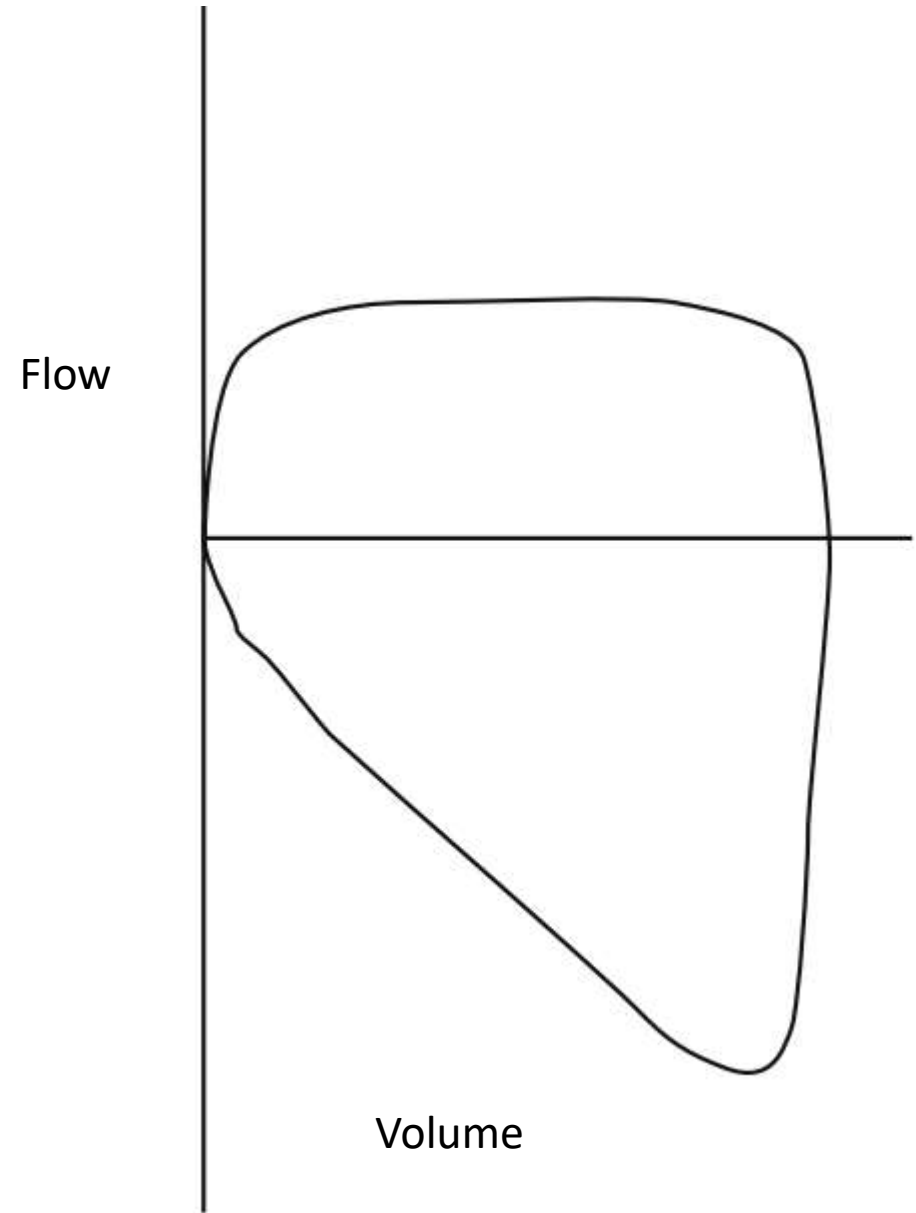
Inspiratory Curve plotted above x-axis

Expiratory Curve plotted below x-axis

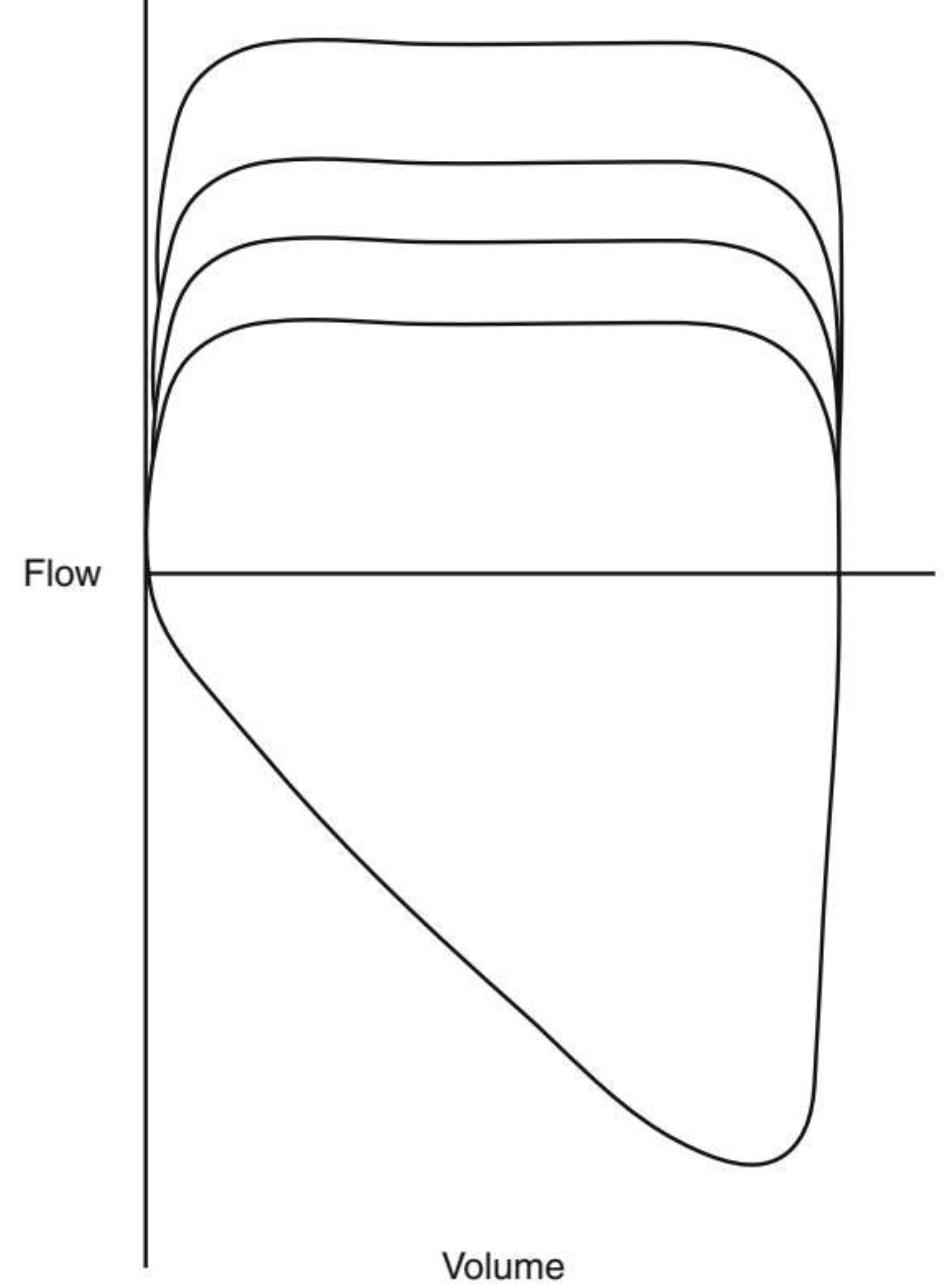
F-V Loop in Spontaneous Breath



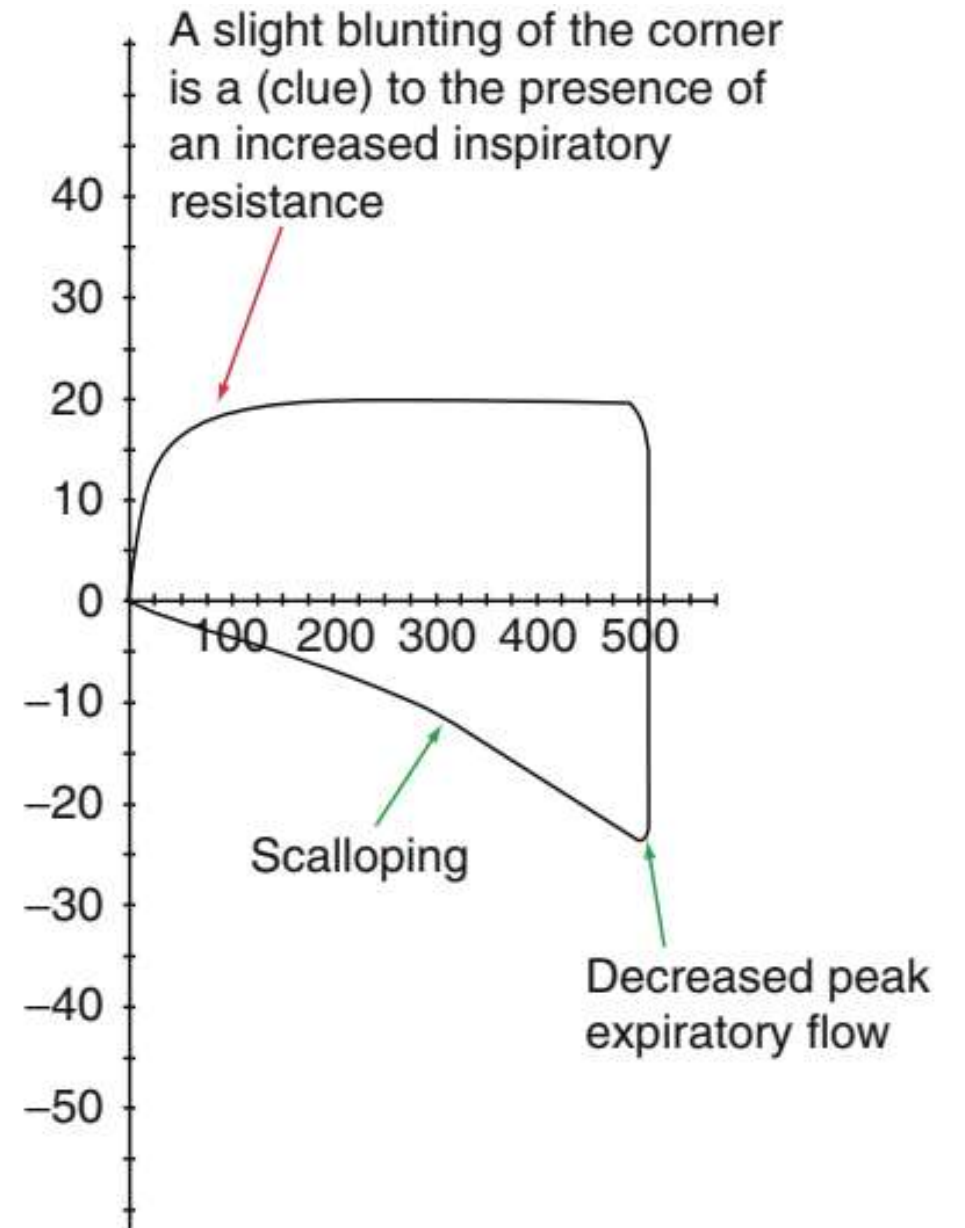
F-V Loop in VCV with
Constant Flow



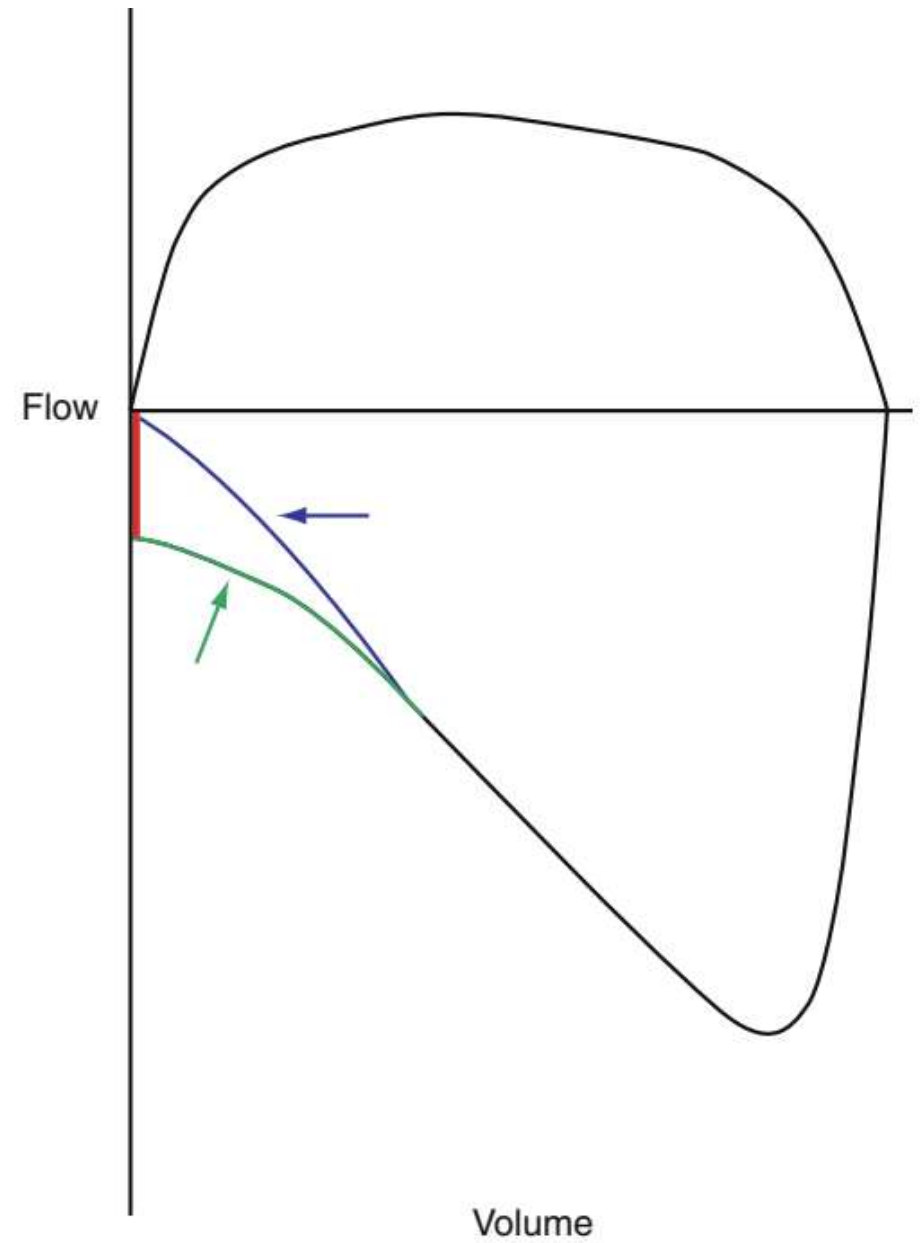
F-V Loop in VCV with different
Constant Flow Rates



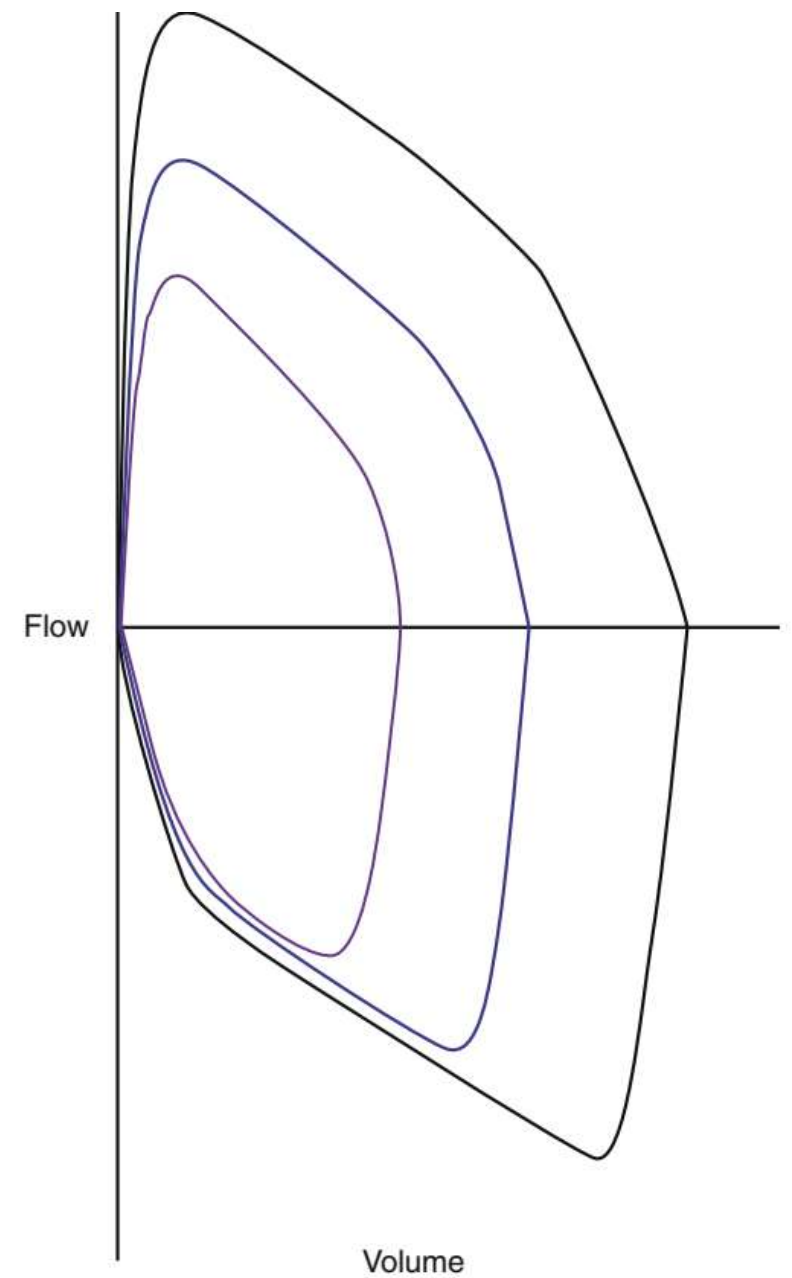
F-V Loop with Airway Resistance



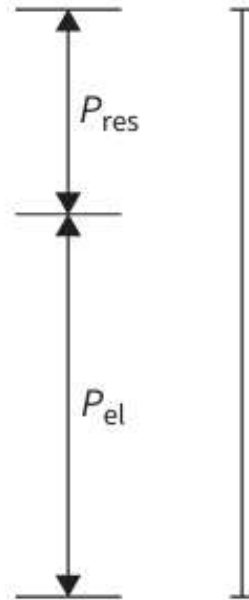
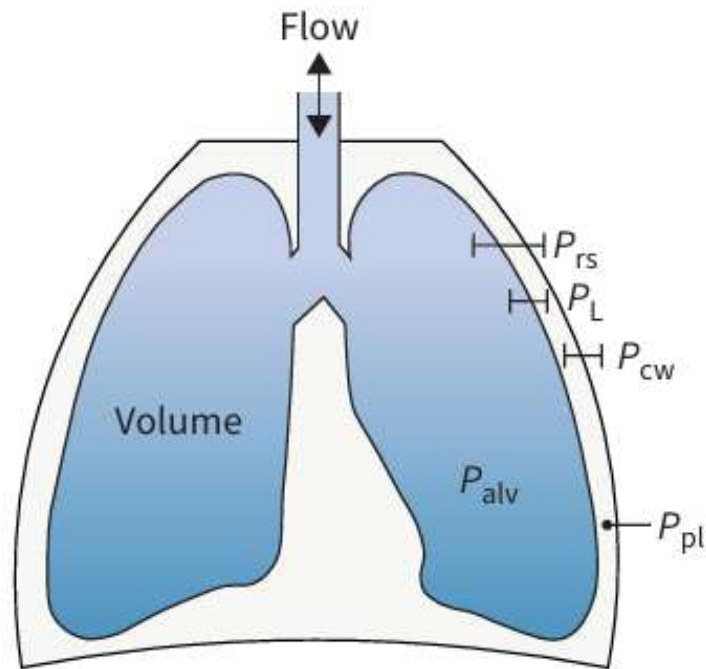
F-V Loop in Air Trapping



F-V Loop in PCV with Different Pressures



Esophageal Catheter

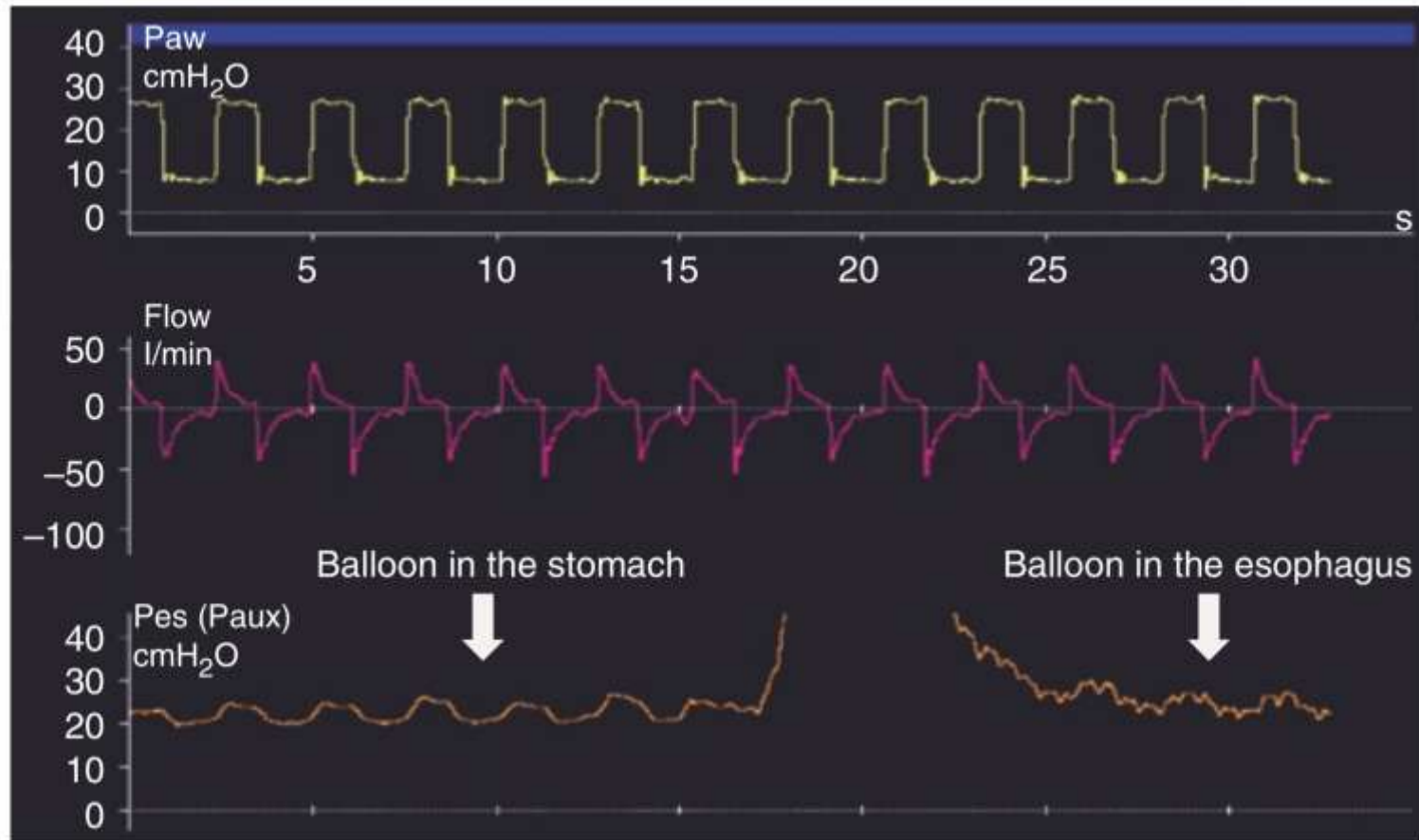


$$P_{tot} = P_{res} + P_{el} + P_0$$

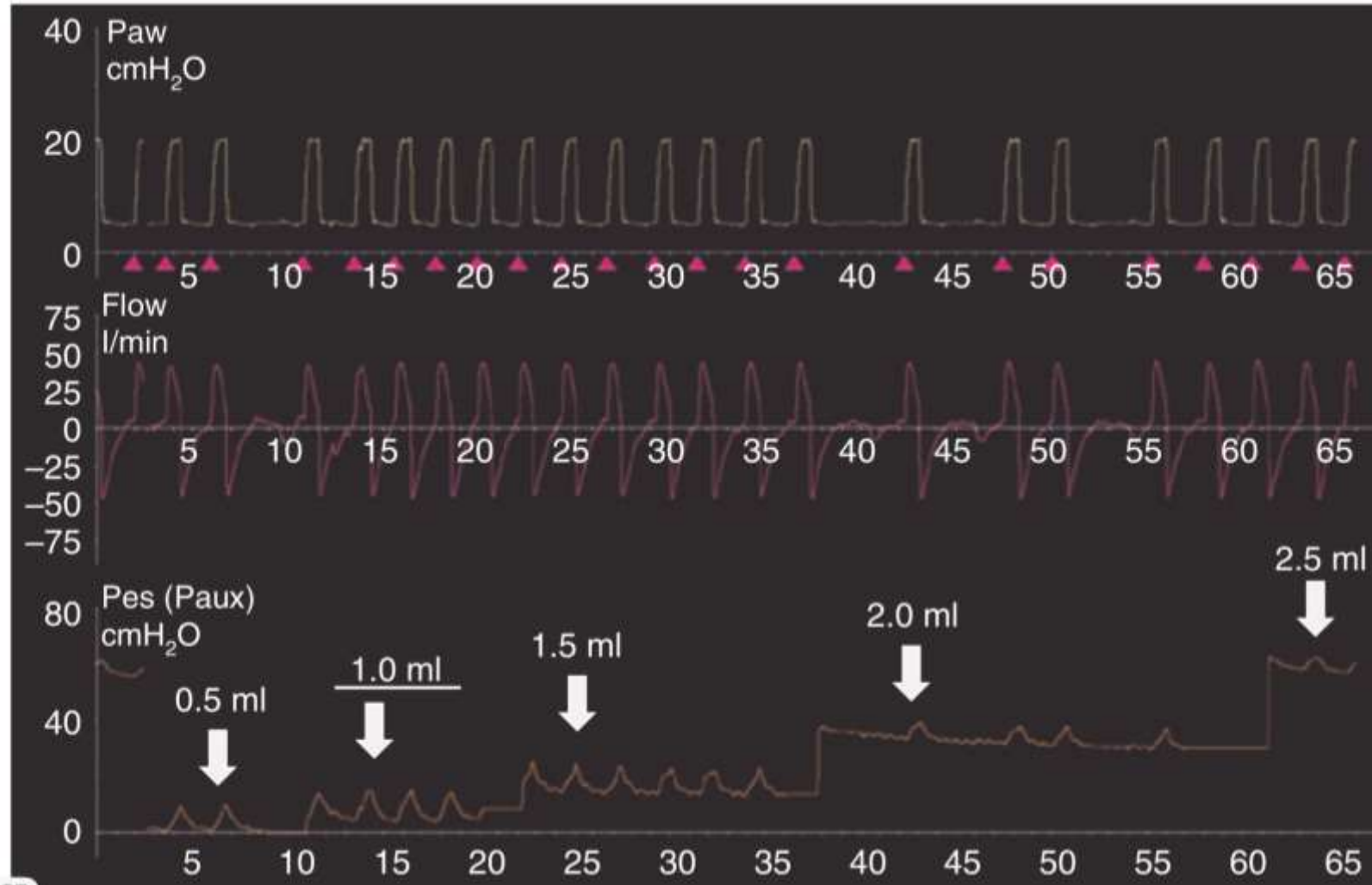
$$P_{tot} = P_{res} + (P_L + P_{cw}) + P_0$$

$$P_{tot} = (\text{flow} \times \text{resistance}) + ((\text{volume} \times E_L) + (\text{volume} \times E_{cw})) + P_0$$

Insertion



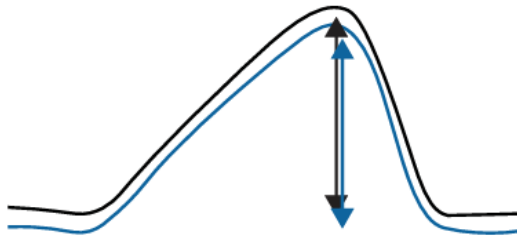
Fix and Inflate



Confirm accuracy of P_{oes} monitoring with the occlusion test

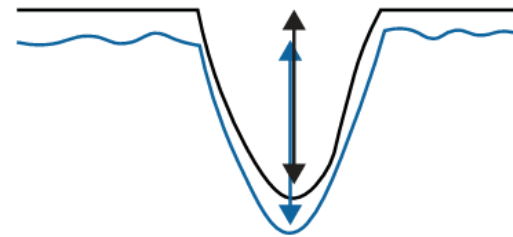
Passive patient

- 1) Perform an end-expiratory occlusion
- 2) Apply a gentle bilateral thoracic compression
- 3) Measure the increase in P_{aw} and P_{oes}



Actively breathing patient

- 1) Perform an end-expiratory occlusion
- 2) Wait for the next occluded inspiratory effort
- 3) Measure the decrease in P_{aw} and P_{oes}

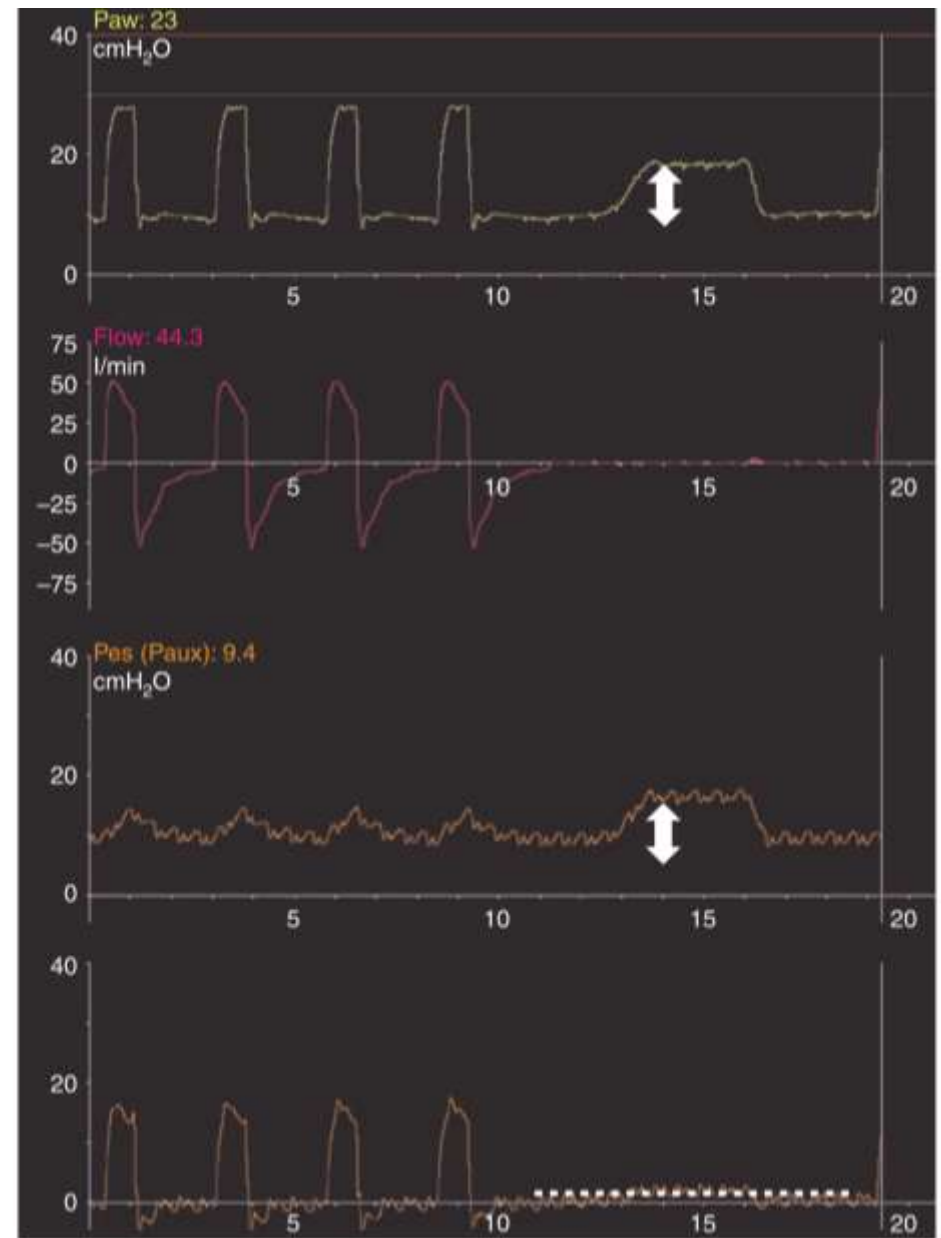


- 4) Check if $\Delta P_{aw}/\Delta P_{oes}$ ratio is within the 0.8–1.2 range

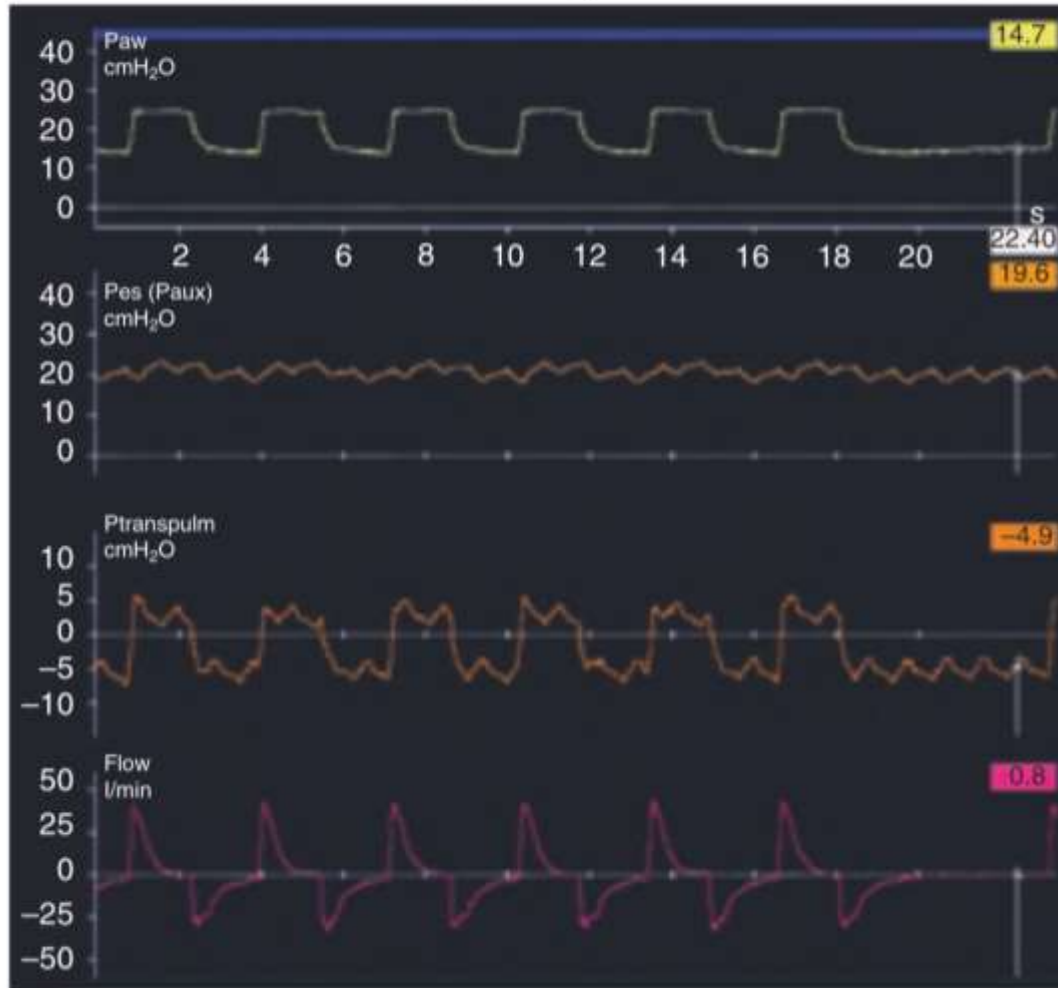
The closer the ratio is to 1, the more precise the P_{oes} measurement is

Out of range? Adjust the catheter position and/or filling volume until accuracy is confirmed

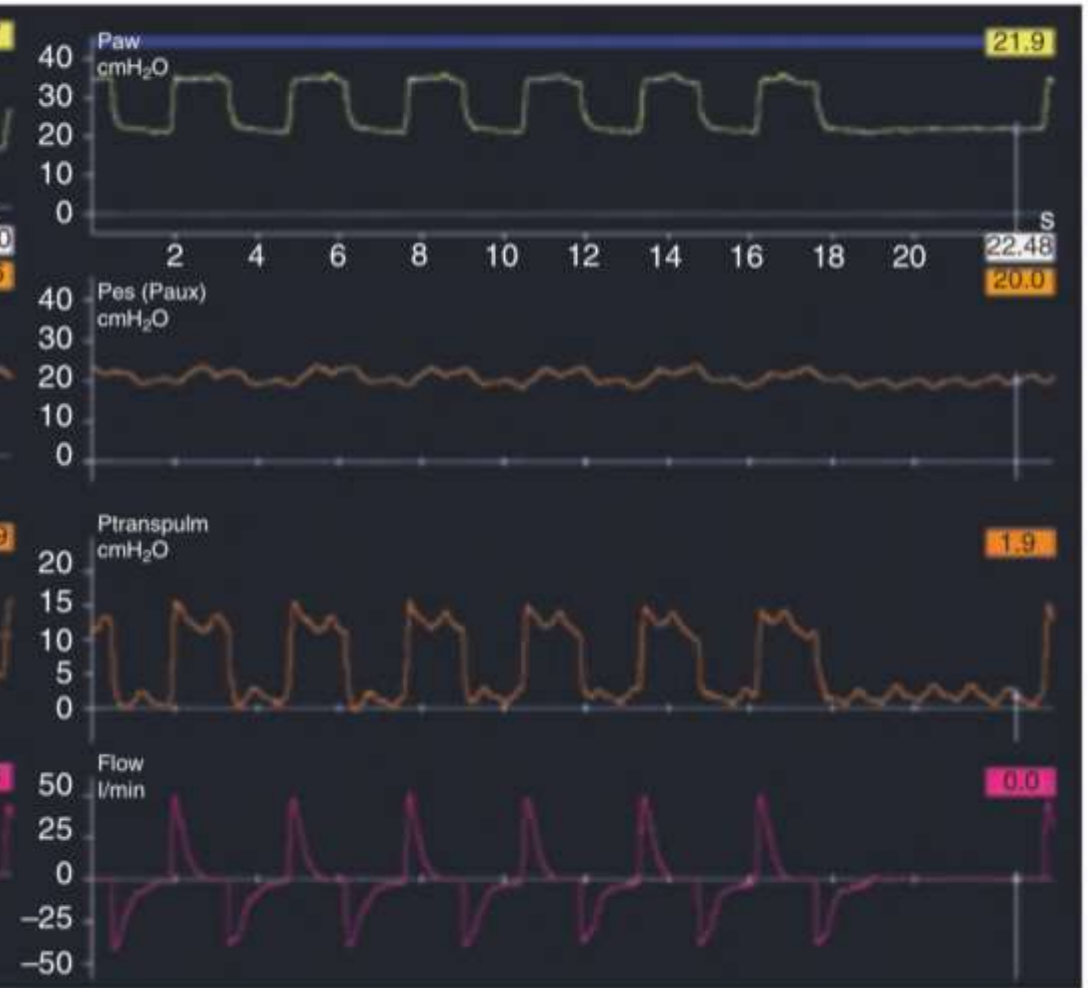
End Expiratory Hold



Negative end-expiratory transalveolar pressure



Positive end-expiratory transalveolar pressure



Target Pressures

End-inspiratory transpulmonary pressure: 20 – 25 cmH₂O

Transpulmonary driving pressure: 10 -12 cm H₂O

End-expiratory transpulmonary pressure: > 0 cm H₂O

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Mechanical Ventilation Guided by Esophageal Pressure in Acute Lung Injury

Esophageal-Pressure–Guided Group

FiO ₂	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9	1.0
P _{Le_{sp}}	0	0	2	2	4	4	6	6	8	8	10	10

Control Group

FiO ₂	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.7	0.8	0.9	0.9	0.9	1.0
PEEP	5	5	8	8	10	10	10	12	14	14	14	16	18	20–24

Table 4. Clinical Outcomes.*

Outcome	Esophageal-Pressure-Guided (N = 30)	Conventional Treatment (N = 31)	P Value
28-Day mortality — no. (%)	5 (17)	12 (39)	0.055
180-Day mortality — no. (%)	8 (27)	14 (45)	0.13
Length of ICU stay — days			0.16
Median	15.5	13.0	
Interquartile range	10.8–28.5	7.0–22.0	
No. of ICU-free days at 28 days			0.96
Median	5.0	4.0	
Interquartile range	0.0–14.0	0.0–16.0	
No. of ventilator-free days at 28 days			0.50
Median	11.5	7.0	
Interquartile range	0.0–20.3	0.0–17.0	
No. of days of ventilation among survivors			0.71
Median	12.0	16.0	
Interquartile range	7.0–27.5	7.0–20.0	

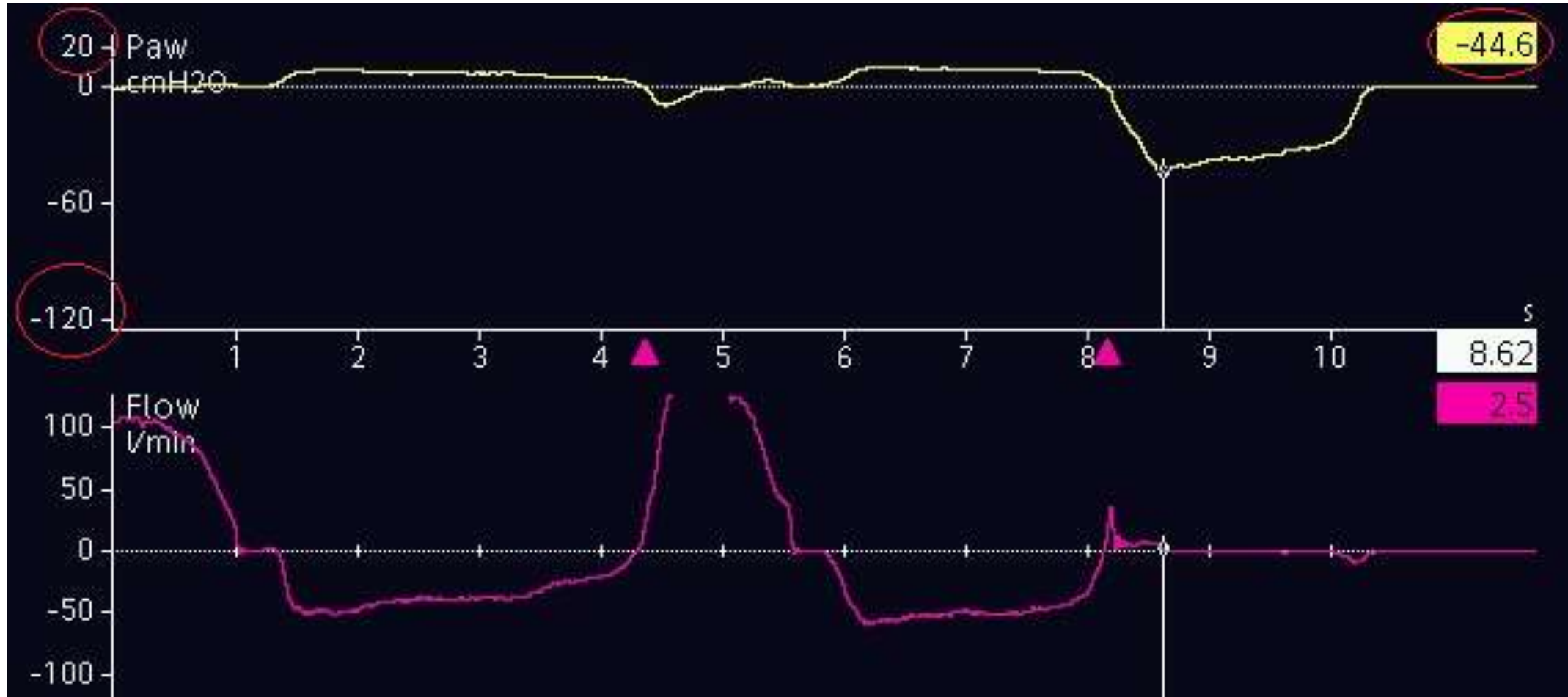
Table 2. Measurements of Ventilatory Function at Baseline and 72 Hours.*

Measurement	Baseline			72 Hr†		
	Esophageal-Pressure-Guided (N=30)	Conventional Treatment (N=31)	P Value	Esophageal-Pressure-Guided (N=29)	Conventional Treatment (N=29)	P Value
PaO ₂ :FiO ₂	147±56	145±57	0.89	280±126	191±71	0.002
Respiratory-system compliance (ml/cm of water)	36±12	36±10	0.94	45±14	35±9	0.005
Ratio of physiological dead space to tidal volume	0.67±0.11	0.67±0.09	0.95	0.61±0.09	0.64±0.10	0.27
PaO ₂ (mm Hg)	91±25	107±44	0.09	124±44	101±33	0.03
FiO ₂	0.66±0.17	0.77±0.18	0.02	0.49±0.17	0.57±0.18	0.07
PEEP (cm of water)	13±5	13±3	0.73	17±6	10±4	<0.001
Tidal volume (ml)	484±98	491±105	0.80	472±98	418±80	0.03
Tidal volume (ml per kg of predicted body weight)	7.3±1.3	7.9±1.4	0.12	7.1±1.3	6.8±1	0.31
Respiratory rate (breaths/min)	26±6	24±6	0.32	26±6	28±5	0.20
Inspiratory time (sec)	0.8±0.1	0.9±0.2	0.19	0.8±0.1	0.8±0.1	0.27
PEEP _{total} (cm of water)	14±5	15±4	0.67	18±5	12±5	<0.001
Peak inspiratory pressure (cm of water)	35±8	35±7	0.85	32±8	28±7	0.007
Mean airway pressure (cm of water)	20±6	20±4	0.88	22±6	16±5	0.001
Plateau pressure (cm of water)	29±7	29±5	0.79	28±7	25±6	0.07
Transpulmonary end-inspiratory pressure (cm of water)	7.9±6.0	8.6±5.4	0.61	7.4±4.4	6.7±4.9	0.58
Transpulmonary end-expiratory pressure (cm of water)	-2.8±5.0	-1.9±4.7	0.49	0.1±2.6	-2.0±4.7	0.06
Esophageal end-inspiratory pressure (cm of water)	21.2±4.9	20.7±5.1	0.68	21.7±7.2	17.9±5.2	0.03
Esophageal end-expiratory pressure (cm of water)	17.2±4.4	16.9±5.0	0.79	18.4±5.9	14.3±4.9	0.008

**Effect of Titrating Positive End-Expiratory Pressure (PEEP)
With an Esophageal Pressure-Guided Strategy vs an Empirical
High PEEP-FiO₂ Strategy on Death and Days Free From
Mechanical Ventilation Among Patients With Acute
Respiratory Distress Syndrome **2019**
A Randomized Clinical Trial**

Variable	PEE- _S -Guided PEEP (n = 102)	Empirical PEEP-FiO ₂ (n = 98)	Absolute Difference, % (95% CI) ^b	P Value ^c
Primary End Point				
Probability of more favorable outcome, a ranked composite incorporating death and days free from mechanical ventilation among survivors, % (95% CI) ^d	49.6 (41.7 to 57.5)	50.4 (42.5 to 58.3)	NR ^e	.92
Secondary Clinical End Points				
Mortality through day 28, No. (%)	33 (32.4)	30 (30.6)	1.7 (-11.1 to 14.6)	.88
Days free from mechanical ventilation among survivors through day 28, median (IQR)	22 (15 to 24)	21 (16.5 to 24)	0 (-1 to 2)	.85
Mortality through day 60, No./total No. (%)	38/101 (37.6)	37/98 (37.8)	-0.1 (-13.6 to 13.3)	>.99
Mortality through 1 y, No./total No. (%)	44/100 (44.0)	44/96 (45.8)	-1.8 (-15.8 to 12.1)	.89
Ventilator-free days through day 28, median (IQR) ^f	15.5 (0 to 23)	17.5 (0 to 23)	0 (0 to 0)	.93
ICU length of stay through day 28, median (IQR), d	10 (6 to 17)	9.5 (5 to 14)	1 (-1 to 3)	.24
Hospital length of stay through day 28, median (IQR), d	16 (9 to 26)	15 (8 to 24)	0 (-1 to 3)	.58
Hospital length of stay through day 60, median (IQR), d	16 (9 to 26)	15 (8 to 24)	1 (-2 to 4)	.47
Rescue therapy administered, No. (%) ^g	4 (3.9)	12 (12.2)	-8.3 (-15.8 to -0.8)	.04
Prone positioning, No. (%)	1 (1.0)	3 (3.1)	-2.1 (-6.0 to 1.8)	.36
Inhaled pulmonary vasodilator, No. (%)	3 (2.9)	10 (10.2)	-7.3 (-14.1 to -0.4)	.046
Extracorporeal membrane oxygenation, No. (%)	1 (1.0)	3 (3.1)	-2.1 (-6.0 to 1.8)	.36
Recruitment maneuvers, No. (%)	1 (1.0)	1 (1.0)	0.0 (-2.8 to 2.7)	>.99
Safety End Points				
Shock-free days, median (IQR) ^f	14 (0 to 21)	17 (0 to 21)	0 (-2 to 0)	.47
Acute kidney injury requiring renal replacement therapy in the first 28 d, No./total, No. (%) ^h	21/100 (21.0)	32/96 (33.3)	-12.3 (-24.7 to 0.0)	.056
Pneumothorax, No. (%)	3 (2.9)	2 (2.0)	0.9 (-3.4 to 5.2)	>.99
Bronchopleural fistula, No.	0	0	0	
Barotrauma, No. (%) ⁱ	6 (5.9)	5 (5.1)	0.8 (-5.5 to 7.1)	>.99

Measurement of Maximal Inspiratory Pressure (MIP)



Thank You
