# Ventilator Management and Troubleshooting

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No conflicts of interest.

# Objectives

Review of terminology, definitions, and modes

Brief look at ventilator waveforms and ventilator interface

Lung injury and obstructive ventilator strategies (practical approach)

Troubleshooting ventilator alarms

When to extubate?

PEEP = EPAP = CPAP (more or less)

Inspiratory pressure = IPAP

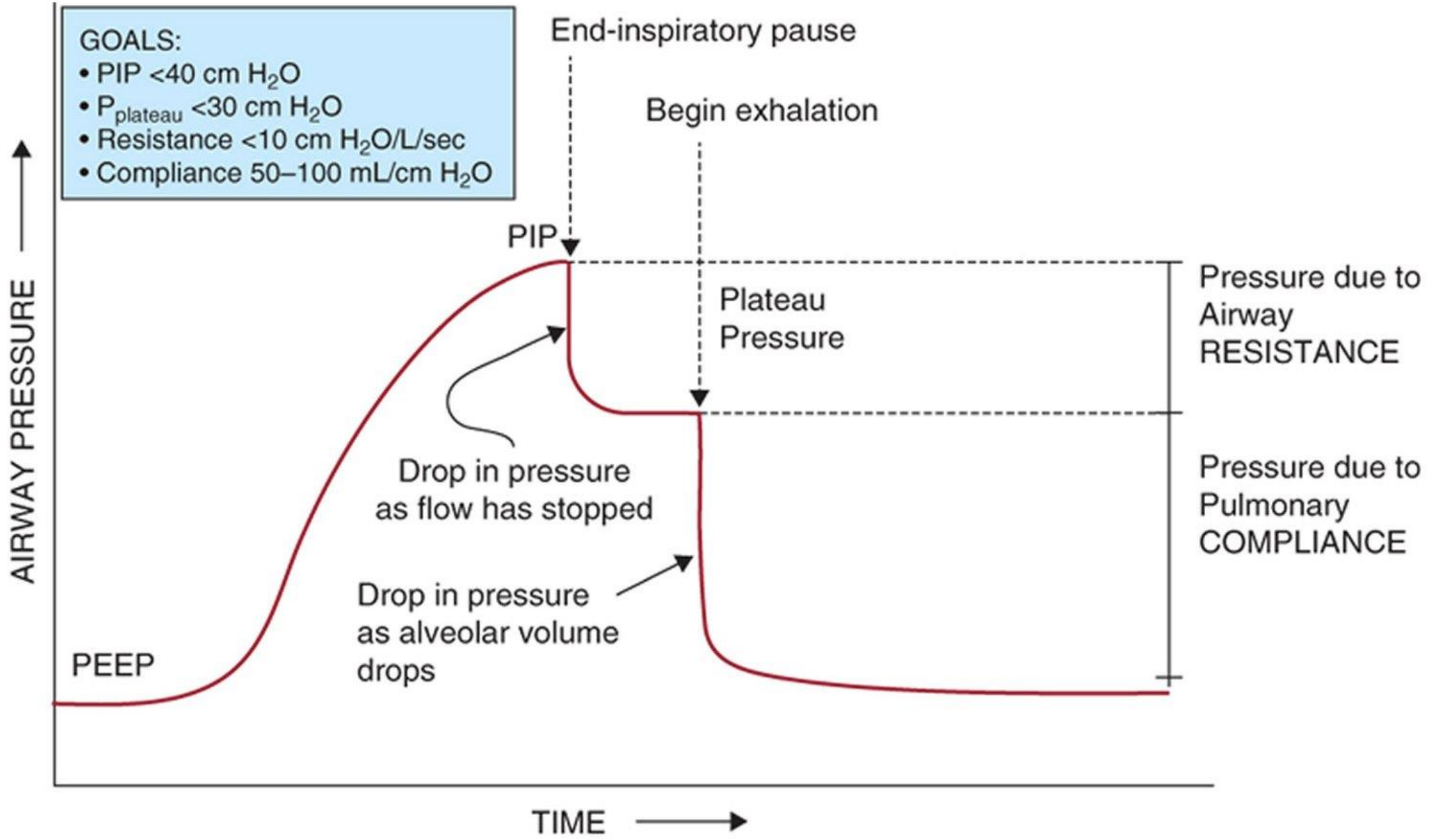
Compliance = change volume / change pressure
- Low > ARDS > "stiff lungs"
- High > emphysema > "floppy lungs"

Resistance = change pressure / change flow

Plateau Pressure = end-inspiration, alveolar pressure, no flow

Peak Pressure = during inspiration/flow, large airways, resistive pressure

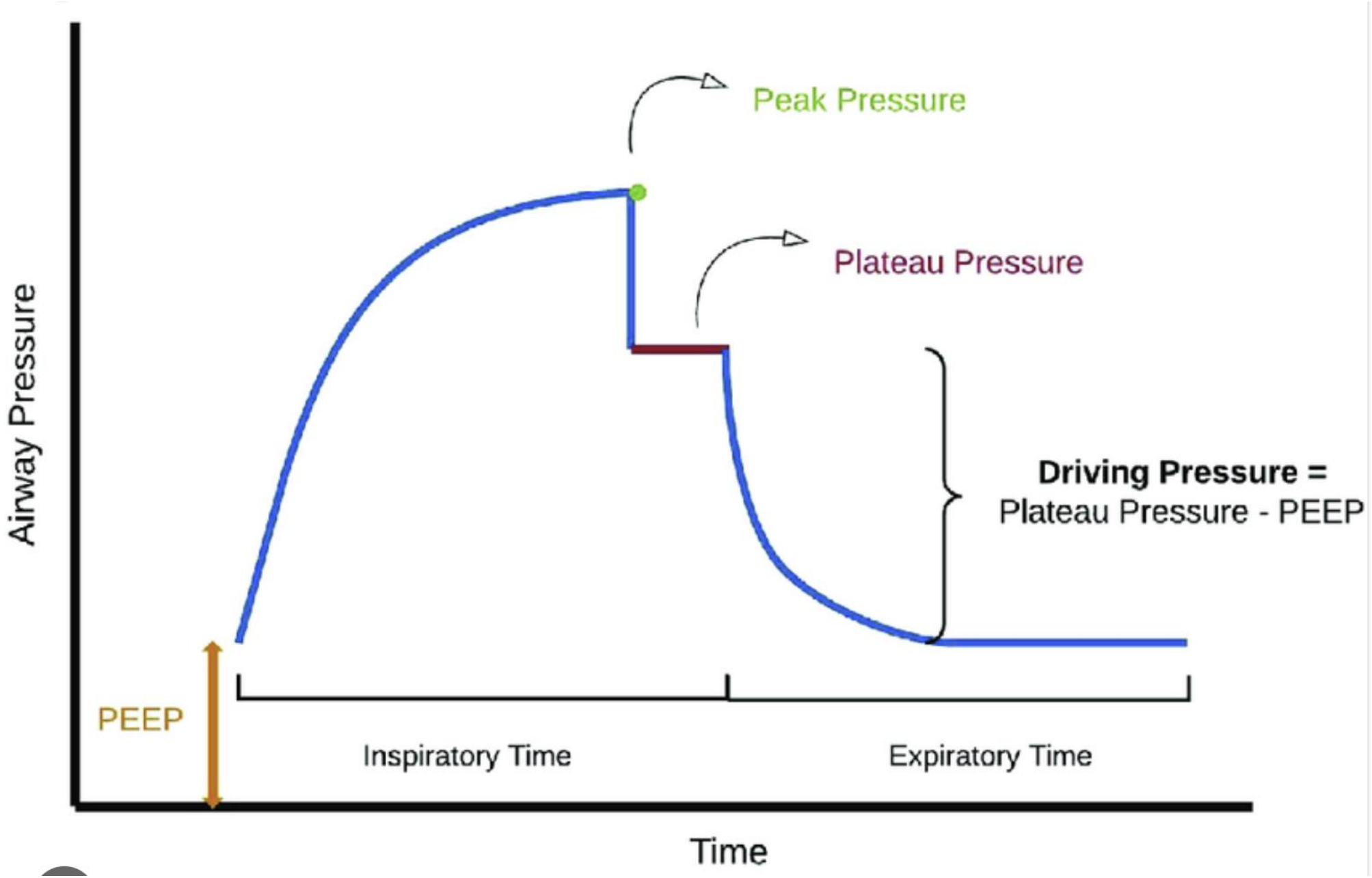
Driving pressure = Plateau – PEEP. Pressure needed to distend lungs



GOALS:
• PIP <40 cm $H_2O$
• $P_{plateau}$ <30 cm $H_2O$
• Resistance <10 cm $H_2O$/L/sec
• Compliance 50–100 mL/cm $H_2O$
End-inspiratory pause
Begin exhalation
PIP
Plateau Pressure
Pressure due to Airway RESISTANCE
Pressure due to Pulmonary COMPLIANCE
Drop in pressure as flow has stopped
Drop in pressure as alveolar volume drops
PEEP
AIRWAY PRESSURE
TIME

I:E ratio (normal 1:2)

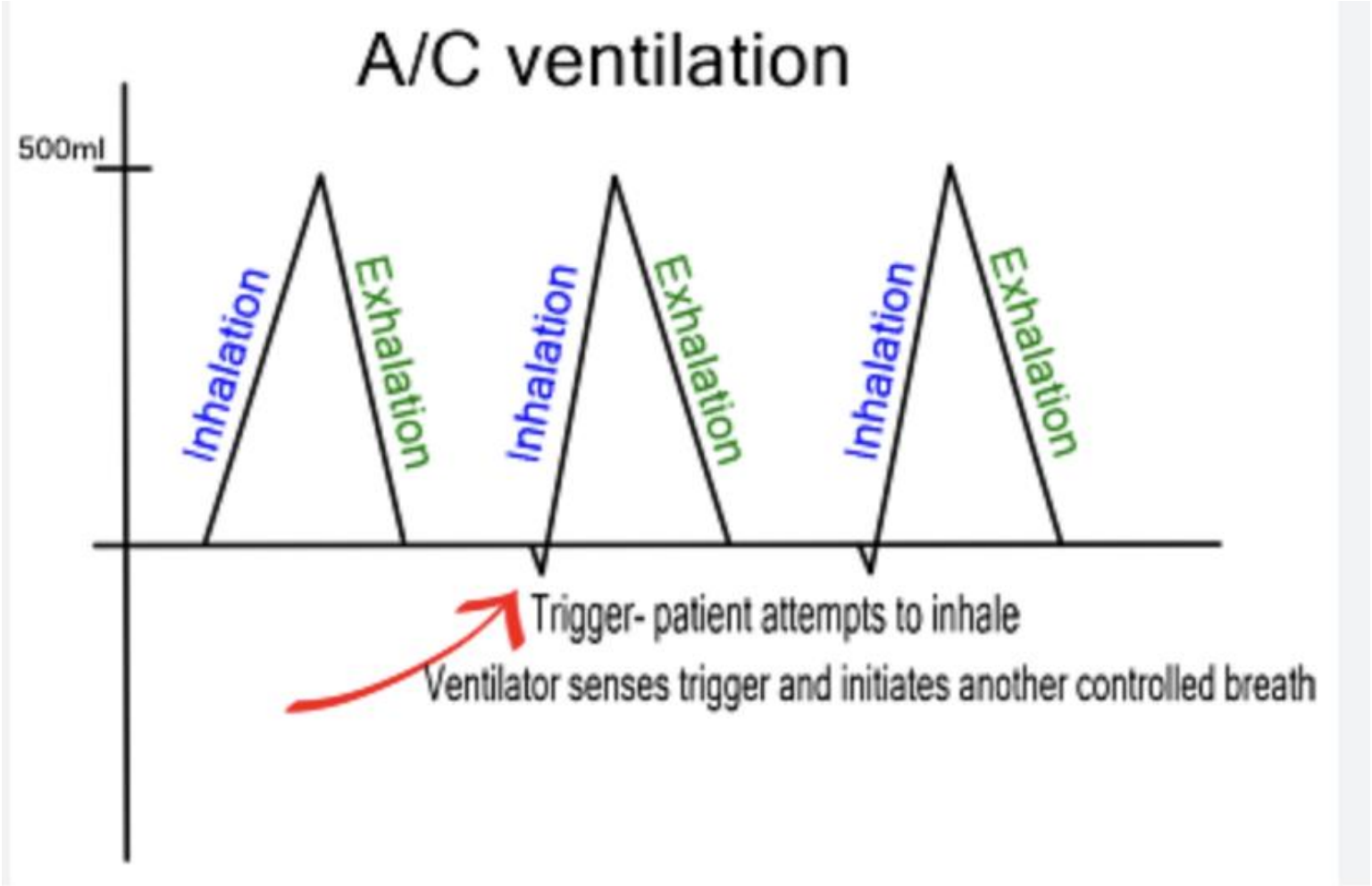
Inspiratory time = inspiratory flow, tidal volume, respiratory rate, square vs decelerating ramp

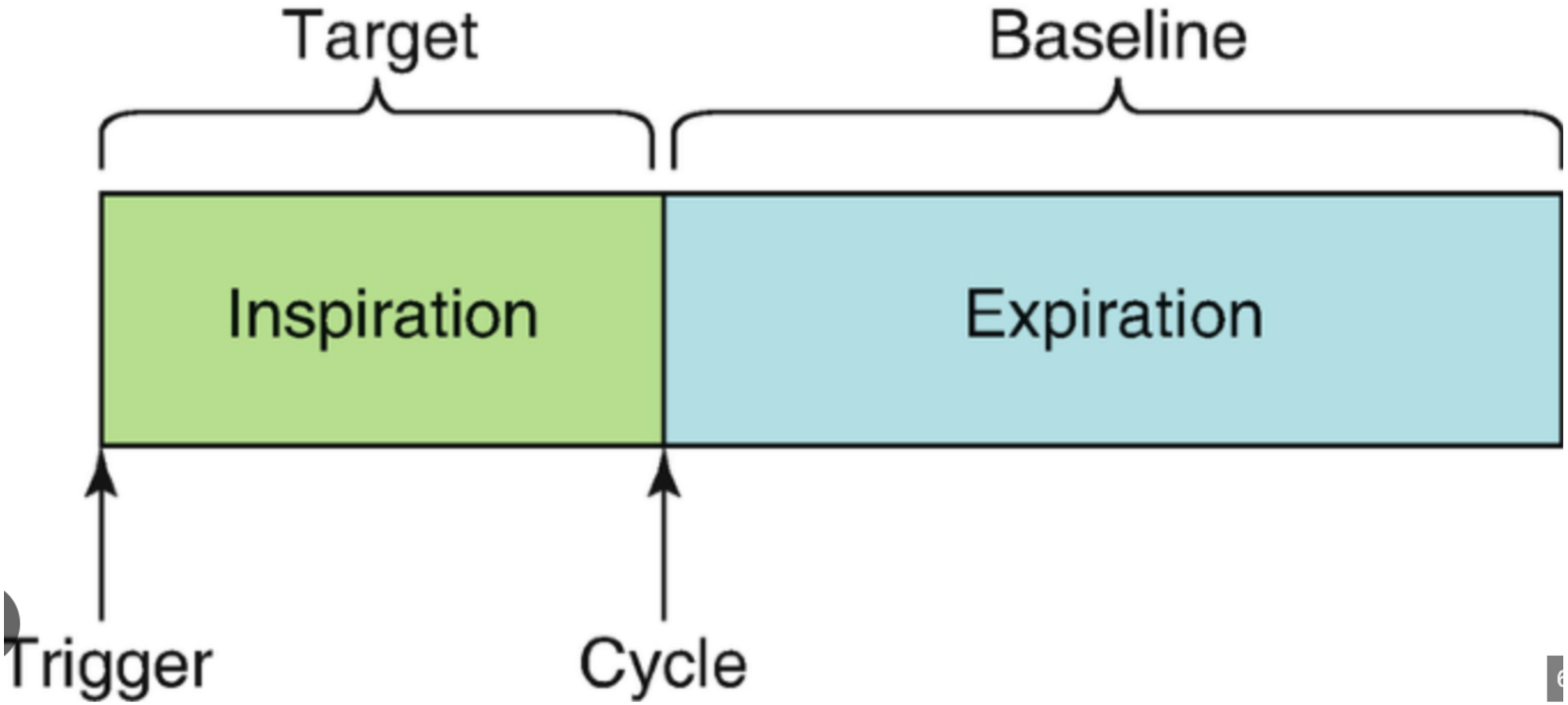
Expiratory time = determined by I-time, not directly set


Peak Pressure
Plateau Pressure
Driving Pressure =
Plateau Pressure - PEEP
Airway Pressure
PEEP
Inspiratory Time
Expiratory Time
Time

# Mechanical Ventilator Breaths & Pull-Ups

| Controlled Breath | Assisted Breath | Supported Breath |
|---|---|---|
| No Work | Start Work | Able to do Some or Most of Work |
| Ventilator Does All the Work | Ventilator Takes Over Work | Ventilator Assists to Finish Work (i.e. Pressure Support) |


A/C ventilation
500ml
Inhalation
Exhalation
Inhalation
Exhalation
Inhalation
Exhalation
Trigger- patient attempts to inhale
Ventilator senses trigger and initiates another controlled breath


Target
Baseline
Inspiration
Expiration
Trigger
Cycle

| Basic Breaths | Trigger | Limit/Target | Cycle |
|---|---|---|---|
| Volume Control | Time | Flow | Volume |
| Volume Assist | Patient Effort | Flow | Volume |
| Pressure Control | Time | Pressure | Time |
| Pressure Assist | Patient Effort | Pressure | Time |
| Volume Support | Patient Effort | Adjusted Pressure (to meet a preset volume target) | % Peak Inspiratory Flow |
| Pressure Support | Patient Effort | Pressure | % Peak Inspiratory Flow |

# Ventilator Modes

| CLINICAL OBJECTIVE | CMV: Mandatory Breaths Only | | | CSV: Spontaneous Breaths Only | | |
|---|---|---|---|---|---|---|
| | PC-CMVs | VC-CMVs | PC-CMVa[1] | PC-CSVs | PC-CSVa[1] | PC-CSVr |
| Minute Ventilation | set rate NOT $V_T$ | set rate AND $V_T$ | set rate AND $V_T$ | MV uncertain | set $V_T$ NOT rate | set WOB NOT rate |
| Prevent VILI[2] | passive | active and passive | passive-some active | no protection | some protection | no protection |
| Synchrony | flow synch | flow & cycle dissync | flow synch | flow & cycle synch | flow & cycle synch | flow/cycle/WOB synch |
| WOB Support (Pvent) | Pvent constant | Pvent ↓ with effort | Pvent ↓ with effort | Pvent constant | Pvent ↓ with effort | Pvent ↑ with effort |
| Liberation | no helpful features | no helpful features | possible auto-wean | no helpful features | possible auto-wean | no helpful features |

[1] *contraindicated if increased respiratory drive (eg, metabolic acidosis)*

Green = OK, Yellow = caution, Red = not recommended

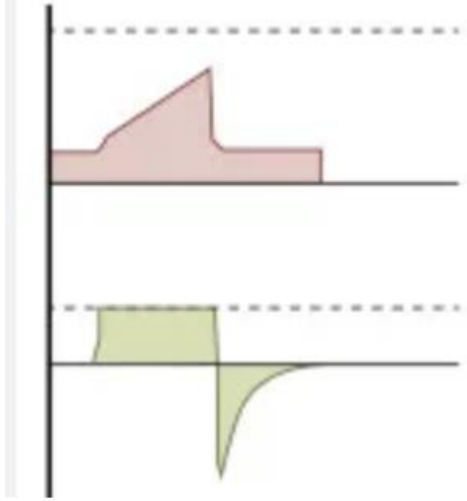
[2] *passive means lung protection for passive ventilation, active means lung protection for active inspiratory efforts*

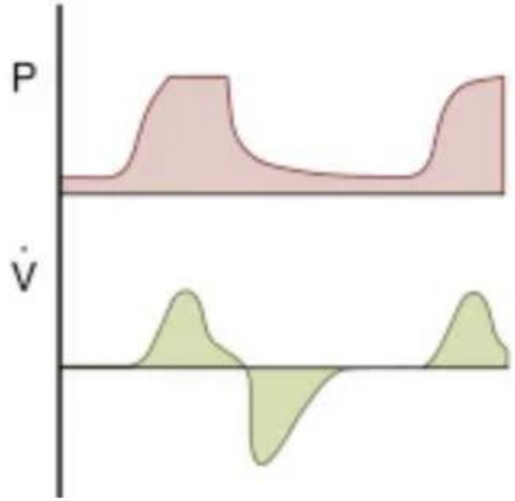
| CLINICAL OBJECTIVE | IMV: Mandatory and Spontaneous Breaths | | | | | |
|---|---|---|---|---|---|---|
| | VC-IMVs,s | | PC-IMVs,s | | PC-IMVa,a | |
| | Mandatory | Spontaneous | Mandatory | Spontaneous | Mandatory | Spontaneous |
| Minute Ventilation | set rate & $V_T$ | MV uncertain | uncontrolled MV | MV uncertain | set rate & $V_T$ | uncertain rate |
| Prevent VILI[2] | active breaths | no protection | passive only* | no protection | active? & passive | active? & passive |
| Synchrony | flow & cycle dissync | flow & cycle synch | flow synch | flow & cycle synch | flow synch | flow & cycle synch |
| WOB Support (Pvent) | Pvent ↓ with effort | Pvent constant | Pvent constant | Pvent constant | Pvent ↓ with effort | Pvent ↓ with effort |
| Liberation | no features | no features | no features | no features | possible auto-wean | possible auto-wean |

# Ventilator Modes

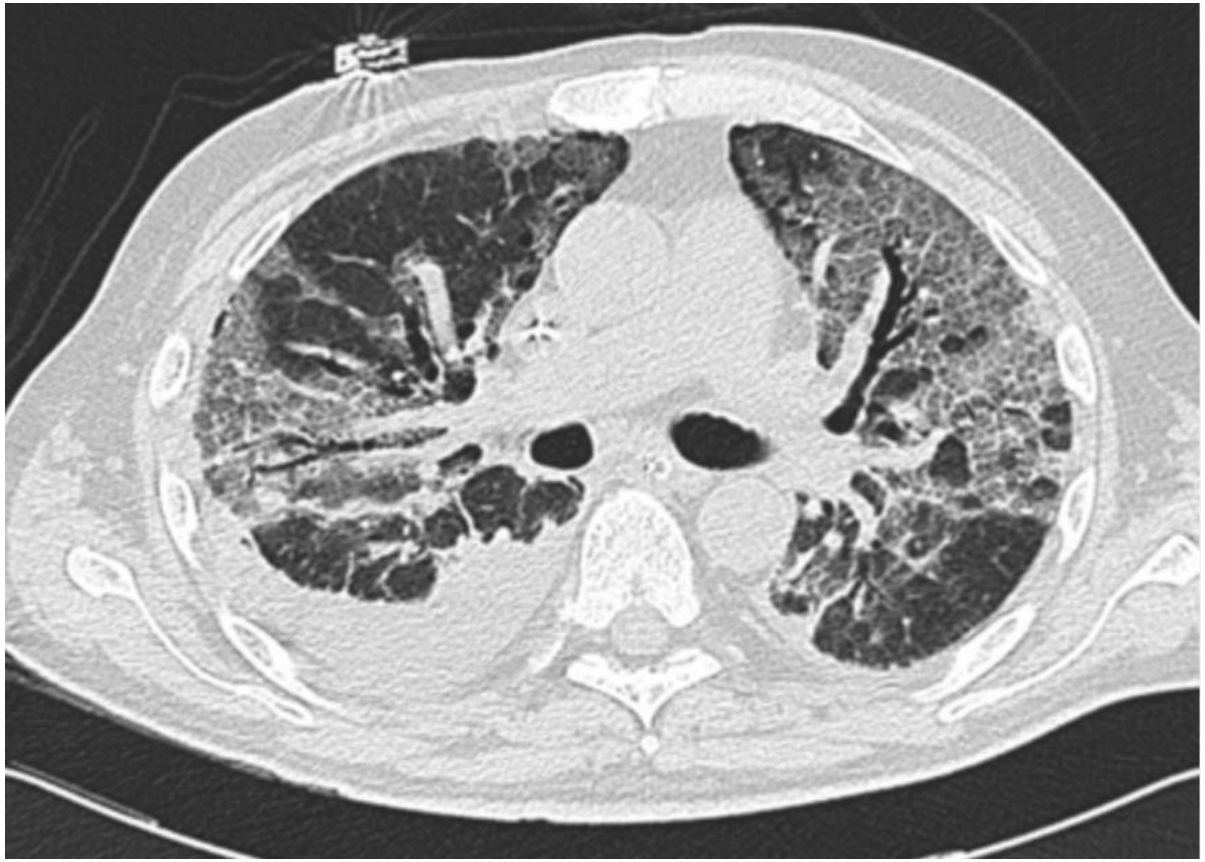
**Volume vs Pressure Ventilation**

| Volume Control | Pressure Control |
| --- | --- |
| - Controls the set flow rate | - Controls the set pressure |
| - Cycles when set volume is delivered | - Cycles by time or flow |
| - Pressure rises passively | - Volume depends on compliance |

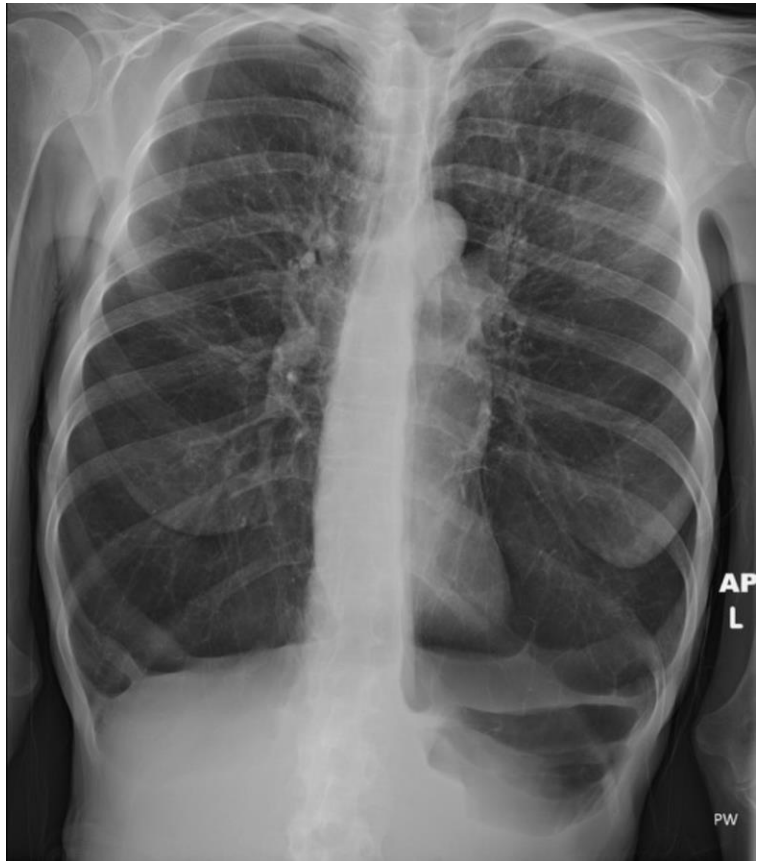




# Lung Injury



# Obstruction



# Lung Injury Strategy


NIH NHLBI ARDS Clinical Network
Mechanical Ventilation Protocol Summary

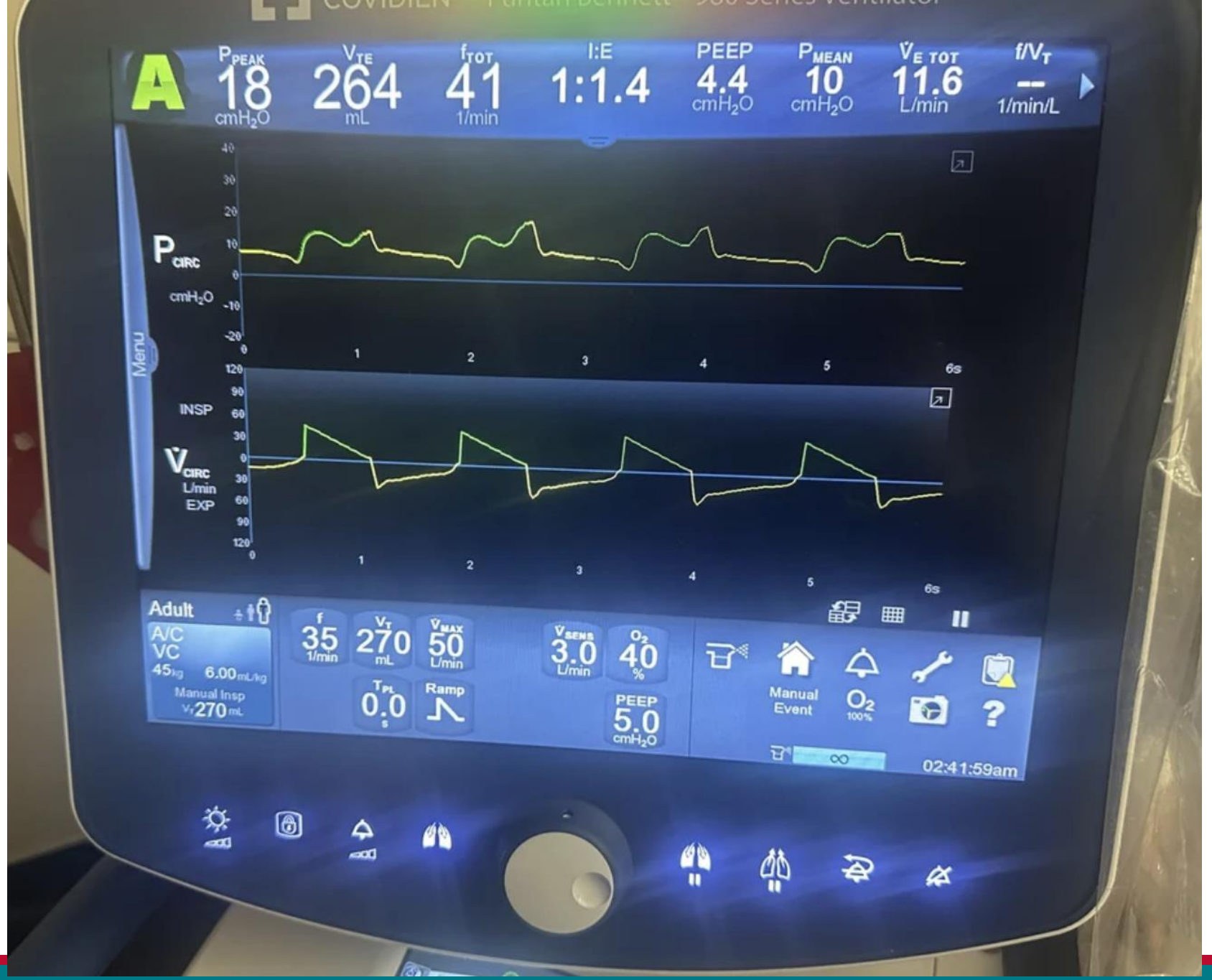
Tidal Volume = Lung Protection. 6-8 cc/kg based upon PBW

Flow rate (IFR) = Comfort. 60-80 lpm

Rate (RR) = Ventilation. Start with rate 16-20. Adjust based upon VBG/ABG. Permissive hypercapnea.

FiO2/PEEP = Oxygenation. Start at 5. Can titrate based on oxygenation, compliance, or driving pressure

Check Plateau Pressure = inspiratory hold, goal < 30. Adjust Vt or PEEP


A
P PEAK 18 cmH2O
V TE 264 mL
f TOT 41 1/min
I:E 1:1.4
PEEP 4.4 cmH2O
P MEAN 10 cmH2O
V̇ E TOT 11.6 L/min
f/VT -- 1/min/L
P CIRC cmH2O
INSP
V̇ CIRC L/min
EXP
Menu
6s
Adult
A/C VC
45kg 6.00mL/kg
Manual Insp
VT 270mL
f 35 1/min
VT 270 mL
V̇MAX 50 L/min
TPL 0.0 s
Ramp
V̇SENS 3.0 L/min
O2 40 %
PEEP 5.0 cmH2O
Manual Event
O2 100%
02:41:59am


P PEAK 39 cmH2O
V TE 426 mL
f TOT 31 1/min
V E TOT 13.1 L/min
P MEAN 24 cmH2O
Respiratory Maneuvers
Inspiratory Pause
Expiratory Pause
Vital Capacity
P0.1
NIF
Menu
Inspiratory Pause Maneuver
P CIRC
cmH2O
0 1 2 3 4 5 6s
Maneuver Completed
Cancel
START
Date Time
P PL cmH2O
C STAT mL/cmH2O
R STAT cmH2O/L/s
07:29am 09-Feb-2019 29 (43) --
Reject
Accept
07:28am 09-Feb-2019 28 (44) --
08:20am 08-Feb-2019 (26) (48) --
08:15am 08-Feb-2019 27 (48) --
Close

**OXYGENATION GOAL: $PaO_2$ 55-80 mmHg or $SpO_2$ 88-95%**

Use a minimum PEEP of 5 cm $H_2O$. Consider use of incremental $FiO_2$/PEEP combinations such as shown below (not required) to achieve goal.

**Lower PEEP/higher FiO2**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **$FiO_2$** | 0.3 | 0.4 | 0.4 | 0.5 | 0.5 | 0.6 | 0.7 | 0.7 |
| **PEEP** | 5 | 5 | 8 | 8 | 10 | 10 | 10 | 12 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **$FiO_2$** | 0.7 | 0.8 | 0.9 | 0.9 | 0.9 | 1.0 |
| **PEEP** | 14 | 14 | 14 | 16 | 18 | 18-24 |

**Higher PEEP/lower FiO2**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **$FiO_2$** | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.5 |
| **PEEP** | 5 | 8 | 10 | 12 | 14 | 14 | 16 | 16 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **$FiO_2$** | 0.5 | 0.5-0.8 | 0.8 | 0.9 | 1.0 | 1.0 |
| **PEEP** | 18 | 20 | 22 | 22 | 22 | 24 |

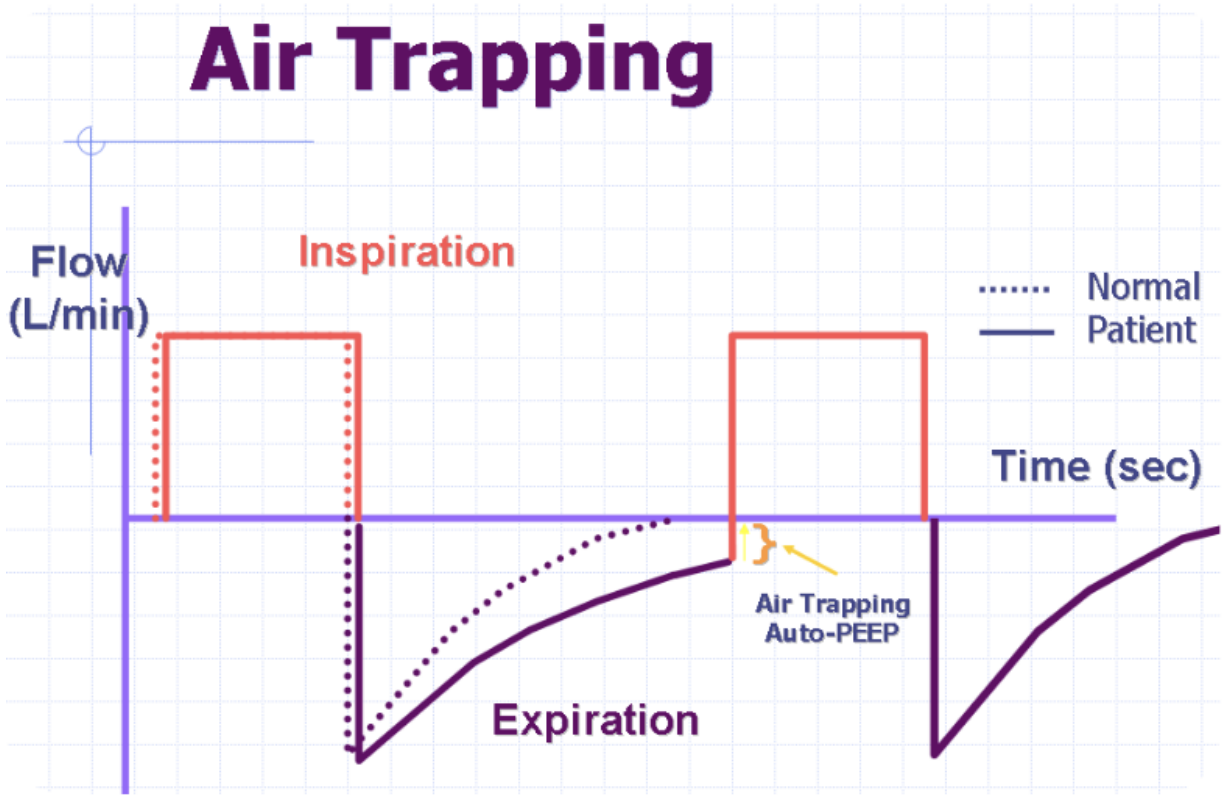
# Obstructive Strategy

Why do we need this?

Emphysema/Asthma/Bronchospasm > Air Trapping

Poor elastic recoil or high resistance
- Inhalation is easy
- Exhalation is impossible

End Result
- Air trapping
- Auto-PEEP
- Dec VR, CV collapse, death



# Obstructive Strategy

Goal = give as much expiratory time as possible

Mode: VC

Tidal Volume: 8 cc/kg PBW

Flow (IFR): 60-100 LPM

PEEP: 5, some use 0

RR: 10-12. Aim for I:E of 1:4 or 1:5

Hypercapnea is expected and ok

Aim for pH 7.1 or higher

CASE REPORTS

## *Management of Massive Grain Aspiration*

Slinger, Peter MD, FRCPC; Blundell, Peter E. MD, FRCSC; Metcalf, Ian R. MB, BS, FFARACS, FRCPC, FANZCA

Author Information

*Anesthesiology* 87(4):p 993-995, October 1, 1997. | *DOI:* 10.1097/00000542-199710000-00039

# Questions?

With those two ventilator strategies in mind, lets looks at some cases...

25M presented to ED with blunt chest trauma and altered mentation. Found to have multiple rib fractures on CXR without pneumothorax. Intubated for airway protection, placed on lung protective ventilation with volume control, TV 400, PEEP 5, and FiO2 50%. Sedated with propofol and fentanyl. Hemodynamically stable and awaiting transport to CT.

Several minutes later the ventilator starts making a lot of noise and flashing lights. You walk over and see the following:


MAQUET
SIMV (PRVC)
+ Pressure Support
Admit patient
Status
Regulation pressure limited
0:14
Ppeak
35
Pmean
13
PEEP
5
RR
31
O2 (%)
45
Ti/Ttot
MVe
0.8
VTi
16.8
VTe
14.3
Save
Quick access
Menu
Main screen
Additional settings
O2 conc.
46
PEEP
5
SIMV rate
30
Tidal Volume
71
Additional values

25M presented to ED with blunt chest trauma and altered mentation. Found to have multiple rib fractures on CXR without pneumothorax. Intubated for airway protection, placed on lung protective ventilation with volume control, TV 400, PEEP 5, and FiO2 50%. Sedated with propofol and fentanyl. Hemodynamically stable and awaiting transport to CT.

Several minutes later the ventilator starts making a lot of noise and flashing lights. You walk over and see the following:

Next Best Steps:

A) Silence the alarm

B) Pretend you don't hear the alarm, someone else will take care of it

C) Increase the peak pressure alarm

D) Check a plateau pressure

You check a plateau pressure and it's > 30

| Increased PIP & PPlat | Increased PIP & Unchanged PPlat |
| --- | --- |
| Acute Respiratory Distress Syndrome (ARDS)<br>Pulmonary Contusion<br>Pulmonary Edema<br>Pleural Effusion (Large)<br>Tension Pneumothorax<br>Circumferential Chest Wall Burn<br>Massive Ascites<br>Abdominal Compartment Syndrome (Or Abdominal Packing)<br>Pneumonia | ETT Occlusion (Kink, Biting)<br>Secretions/Mucous Plugging<br>Bronchospasm |

Your patient has a PTx. Chest tube placed. Both peak and plateau pressures return to baseline

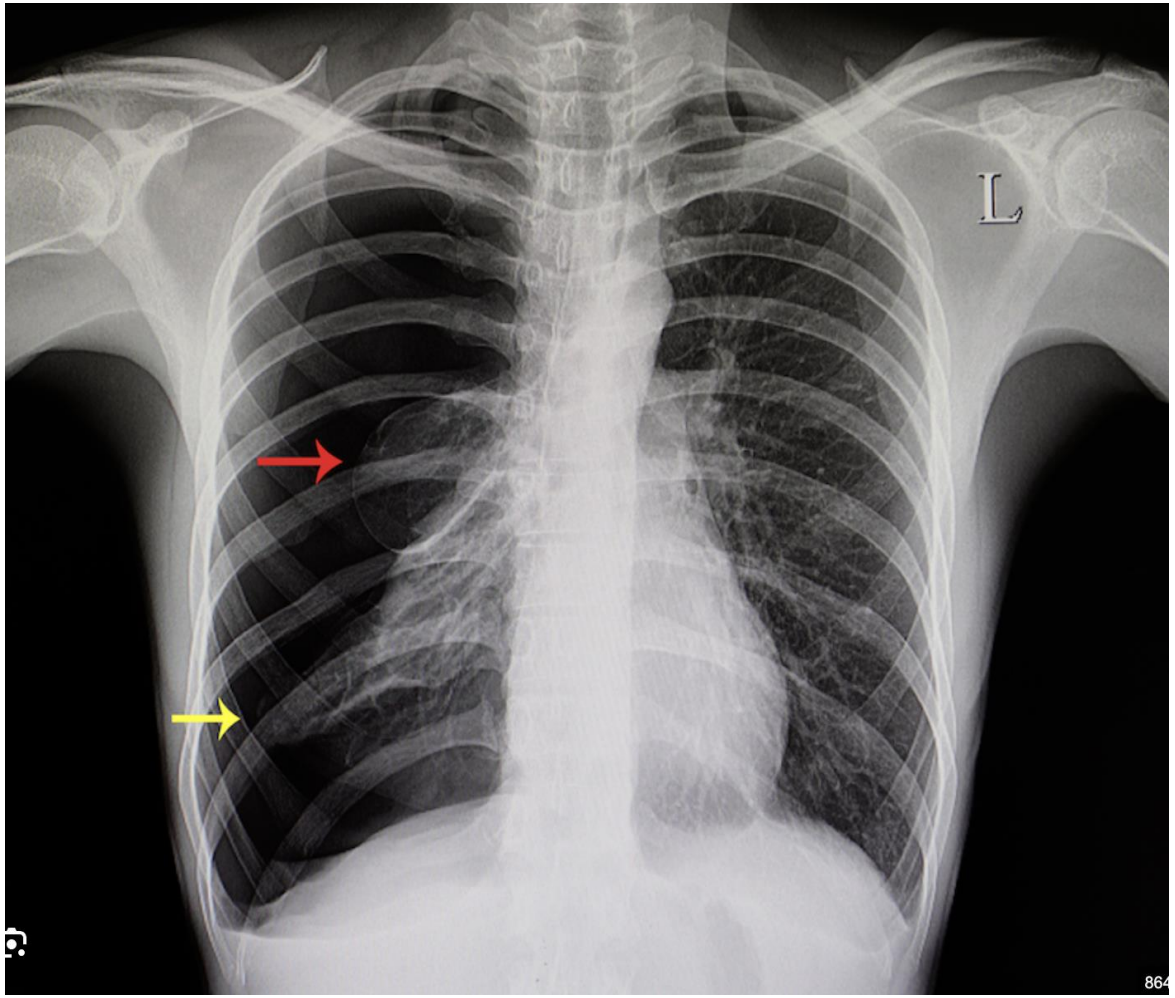


Table 1. DOPES mnemonic

| "DOPES" | Description | Signs | Treatments |
|---|---|---|---|
| **Displaced** | ETT in right main stem, oropharynx, esophagus | Increased or decreased depth at the lip, unequal breath sounds, distended abdomen | Pull tube back, check placement with laryngoscopy, reintubate if necessary |
| **Obstruction** | Mucous plugging, tube biting | Transmitted upper airway sounds, agitation | Deep suctioning, improved sedation |
| **Pneumothorax** | Collapsed lung | Decreased breath sounds, shift of mediastinum, JVD | Needle decompression, tube thoracostomy |
| **Equipment failure** | Ventilator malfunction or disconnection | Vent may alarm | Disconnect the patient and bag |
| **Stacking** | Gas trapping | Extremely high plateau or peak pressures, incomplete return to baseline of flow-versus-time graph | Disconnect and allow for exhale, adjust ventilator settings (pressure control), increase E time, decrease tidal volume, lower PEEP |

75M presented after ground-level fall, found to be altered and intubated for airway protection. Immediately after intubation and upon connecting him to the ventilator with lung protective settings, you notice the patient isn't receiving a tidal volume and peak pressure alarm is flashing. You act quickly and run through the DOPES mnemonic. After connecting him to BVM you notice some resistance with ventilation, but nothing excessive. You re-connect him to the ventilator and the same thing happens. What's going on?

# Peak Pressure Alarm

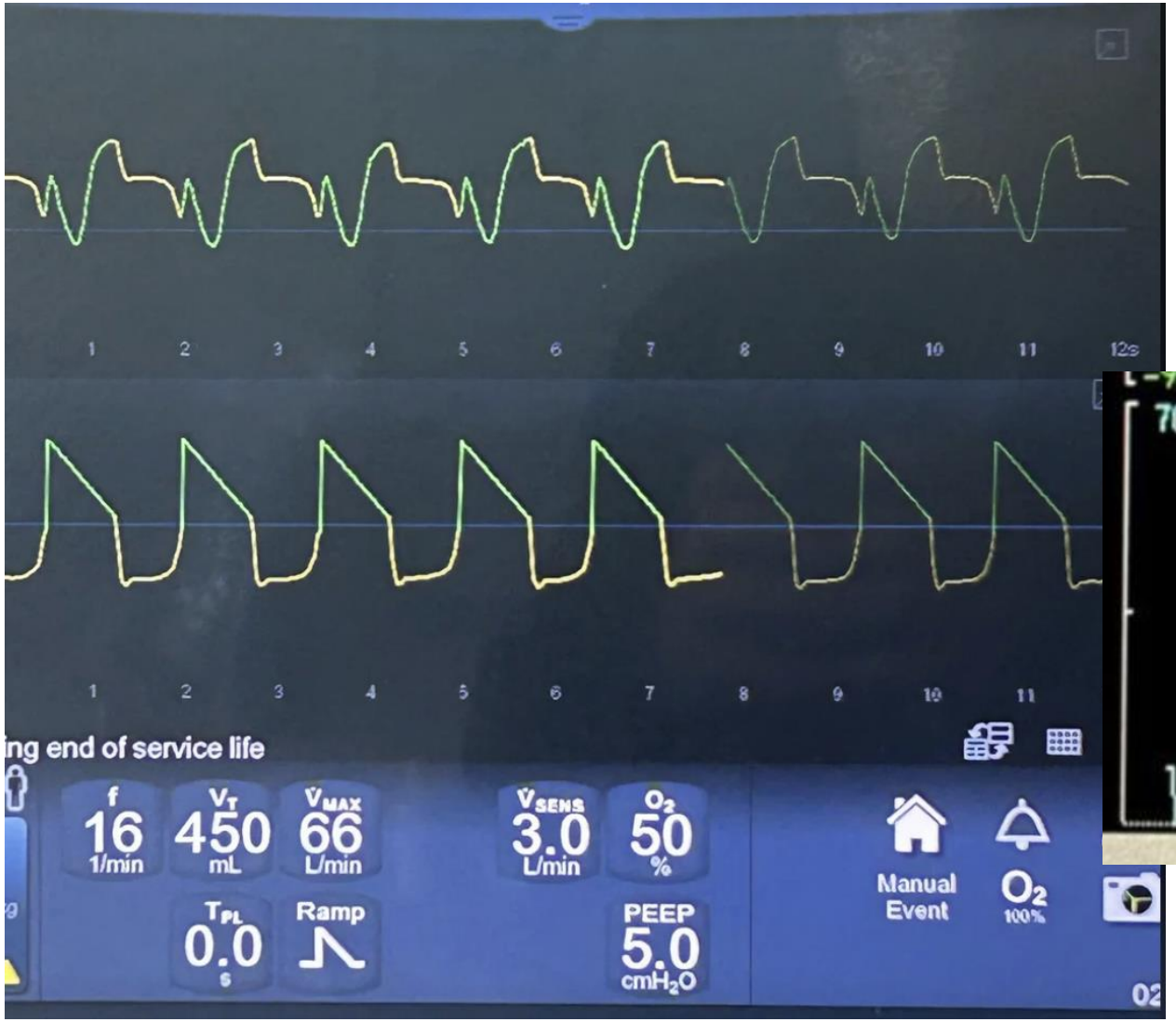
Stops Inspiration = breath is "dropped"

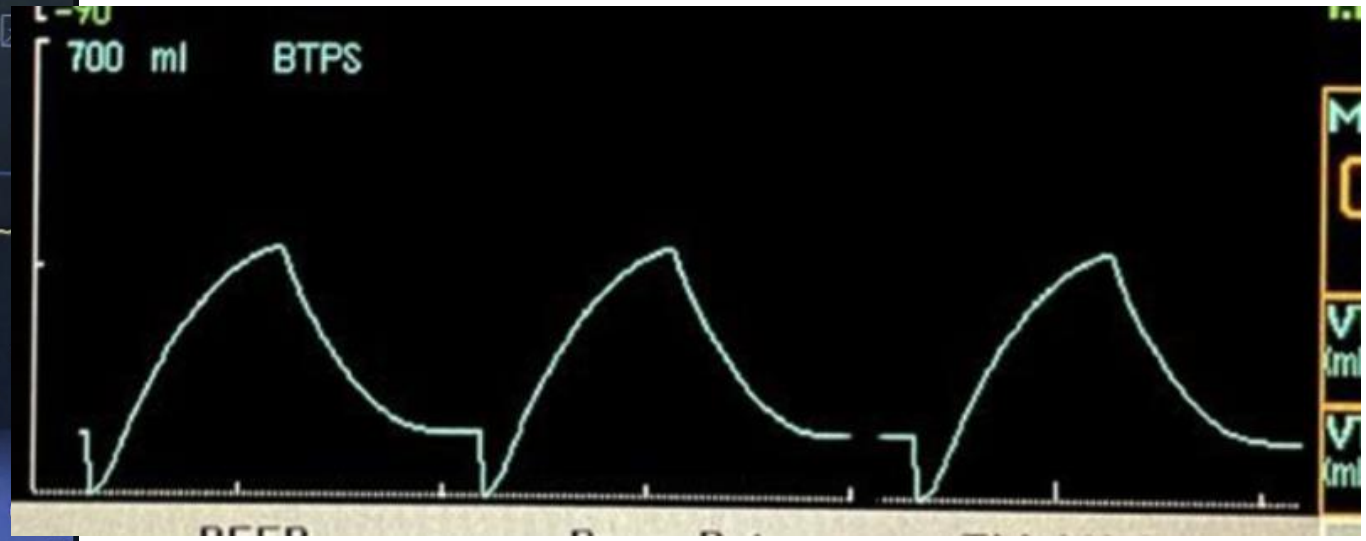
Cycles into exhalation

Triggers a high-pressure alarm

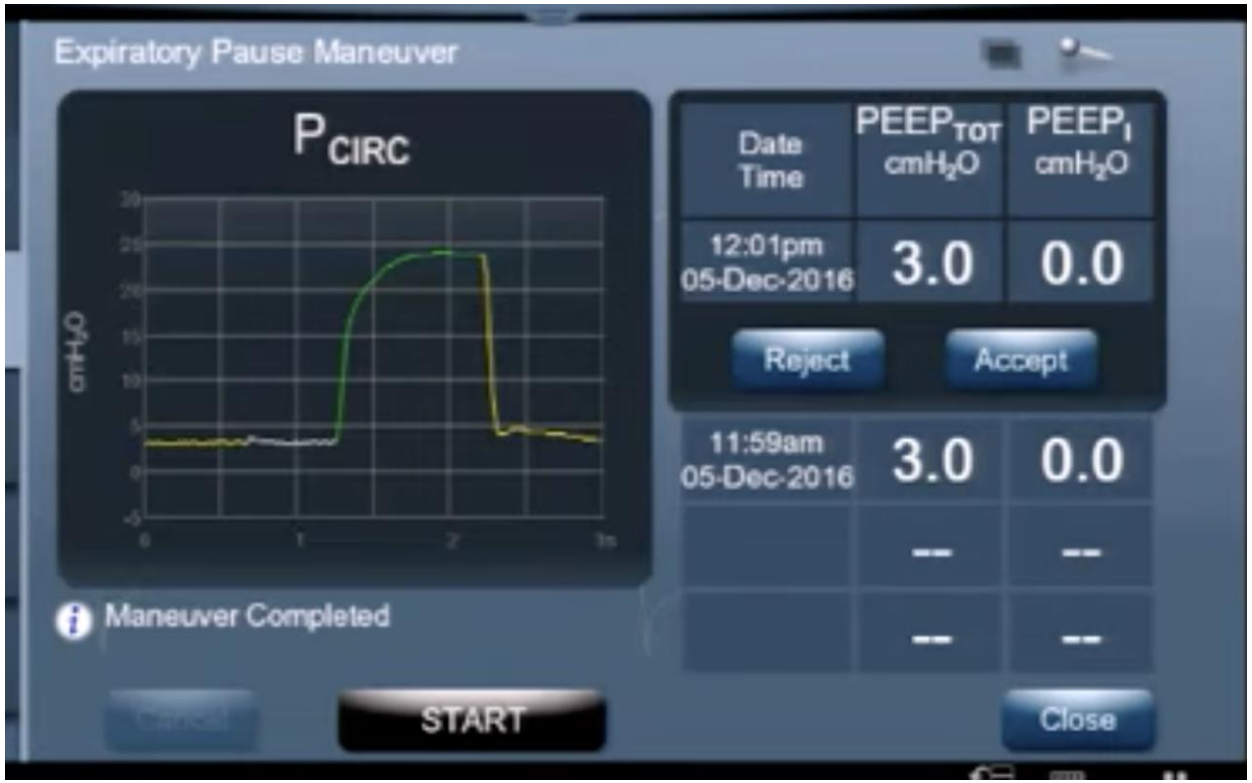
Initially you increased the peak pressure alarm and appropriate tidal volumes were delivered. Once he received volumes wheezing was noted, after an hour and several neb treatments peak pressures subsided and alarm was reset. His family arrives and tell you he has a history of COPD, with a recent hospitalization for exacerbation.  Things are stable for a while, then about an hour later the nurse calls you to bedside because patient's BP has dropped and the peak pressure alarm keeps firing.

You look at his ventilator and see the following:


1 2 3 4 5 6 7 8 9 10 11 12s
1 2 3 4 5 6 7 8 9 10 11
ing end of service life
f 16 1/min
VT 450 mL
V̇MAX 66 L/min
V̇SENS 3.0 L/min
O2 50 %
TPL 0.0 s
Ramp
PEEP 5.0 cmH2O
Manual Event
O2 100%
02


700 ml BTPS

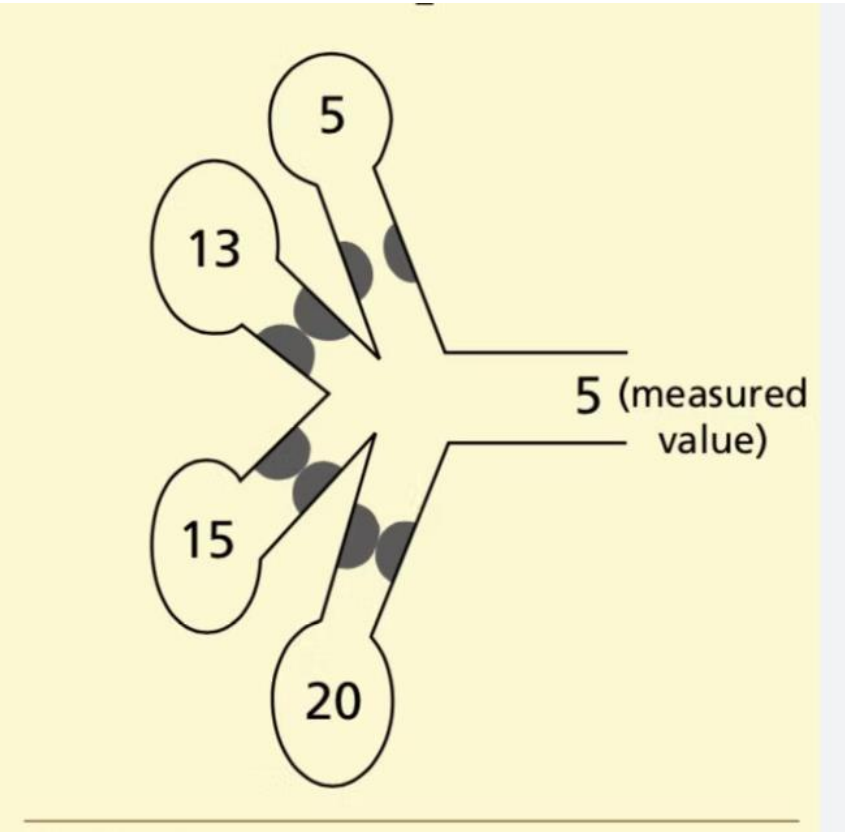
# Air trapping = dynamic hyperinflation = auto-PEEP




## ✅ Summary:

| Feature | Is It on Vent? |
|---|---|
| **Auto-PEEP alarm** | ❌ Not directly |
| **Flow not returning to baseline** | ✅ Yes (visual) |
| **High PIP with normal plateau** | ✅ Yes (suggests resistance) |
| **EEH maneuver to measure auto-PEEP** | ✅ Yes (manual) |

Expiratory pause reveals total-PEEP 15 and intrinsic-PEEP of 10. You quickly realize what's going on, refer to DOPES mnemonic, disconnect the patient from the ventilator, push on his chest and appreciate a large whoosh of air. You aggressively treat his bronchospasm and place him on an obstructive ventilator strategy. BP improves. Repeat expiratory pause shows total-PEEP 7 and intrinsic-PEEP of 2.




What amount of auto-PEEP is normal or ok?

Normal is essentially 0

What is permissible is debatable. Goal < 5, or whatever you can achieve without excessive hypercapnea/acidosis, plateau pressures < 30, hypotension, etc

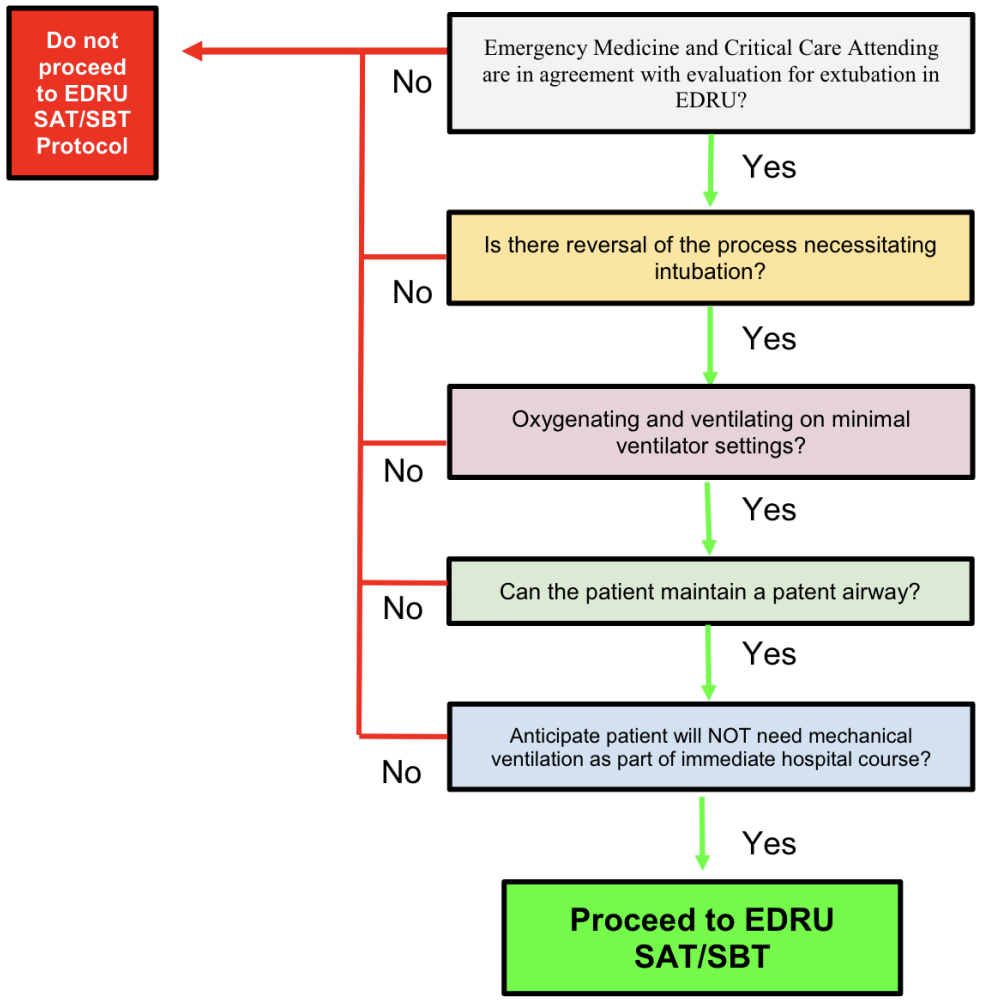
19M presents after motorcycle collision, altered, with high suspicion for severe TBI. Intubated for airway protection and placed on lung protective ventilation. CT scanner is down and will be several hours before operational. As he boards in the ED, what are the TBI specific considerations when it comes to mechanical ventilation?

| | | Evidence |
|---|---|---|
| Mode | Volume or Pressure Control | None |
| Tidal Volume | 6-8 mL/kg | ARDSnet |
| PEEP | Avoid high unless ICP monitor available, 5-8 cm H2O | None |
| PaO2 | ➢ 60, 80-120 mmHg preferred | NCC guidelines |
| PaCO2 | ➢ 35-45 mmHg | NCC guidelines |

*Minimize dyssychrony due to increased ITP and reduced cerebral venous return

Several hours elapse and patient gets his CT which is read as normal. His ethanol level came back at 400. Several more hours elapse and now the patient is awake and moving around, slowly starting to follow commands. Does this patient need to stay intubated?

# EDRU EXTUBATION CHECKLIST




**Consider extubation in patients with:**

-Resolved intoxications/overdoses
-Minor head injuries without significant trauma or intracranial bleeding

**Minimal Vent Settings**

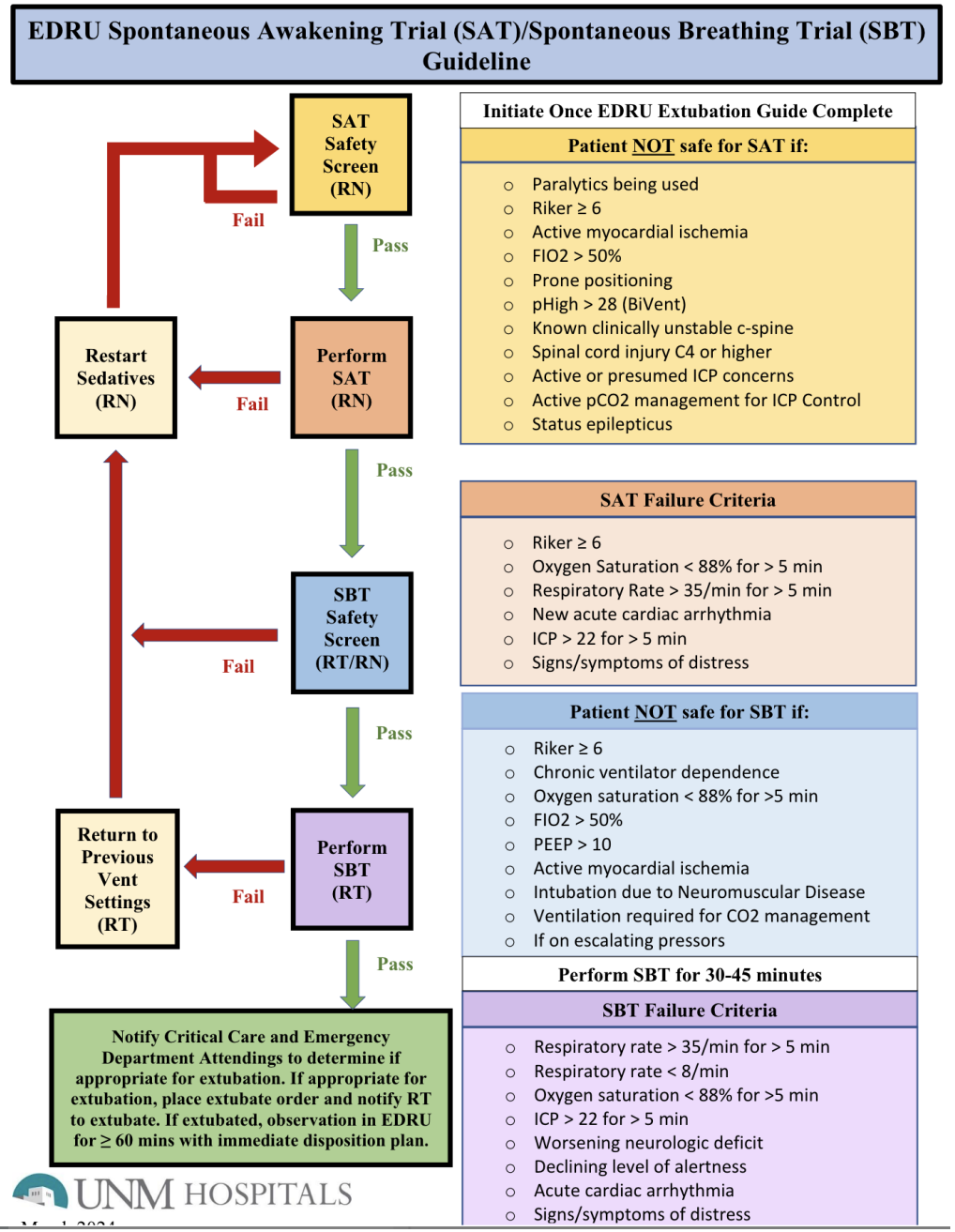
-Spontaneous ventilation mode with pressure support ≤ 5
-PEEP ≤ 5
-Tidal Volume ≥ 5 cc/kg

**Maintaining Patent Airway**

-Anatomically normal and with no known upper airway obstruction
-Can follow commands
-Do not anticipate challenging re-intubated

**Considerations**

-Patient is hemodynamically stable
-O2 sat > 92% on FiO2 < 0.5
-HR < 100 BPM
-RR < 30/min
-SBP > 90 mm Hg
-No active cardiac ischemia
-Few secretions
-No imminent surgery or transport




SAT = sedation off. Will patient protect their airway? Cough? Secretions? Ability to move their head? Don't have to be following commands.

SBT = PS 5/5 on 50% or less. 30-60 minutes. Can they maintain a consistent minute ventilation and oxygen saturation? Do I need a repeat blood gas?

Tachypnea not always = weakness

Tachypnea with large TV = anxiety, neuro, pain, acidosis

Tachypnea with small TV and/or low Ve = weakness, sedation. Much more concerning.

# Last Couple Considerations....

Transport vents – less customizable, limited flow rates, alarms fixed

Adjust minute ventilation to compensate for metabolic acidosis

6 cc/kg is not a one size fits all model

PEEP can be liberalized in obese patients

# Questions?

# References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