MECHANICAL VENTILATION

Critical Thinking after Intubation

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LOVELL FHCC SIMULATION CENTER
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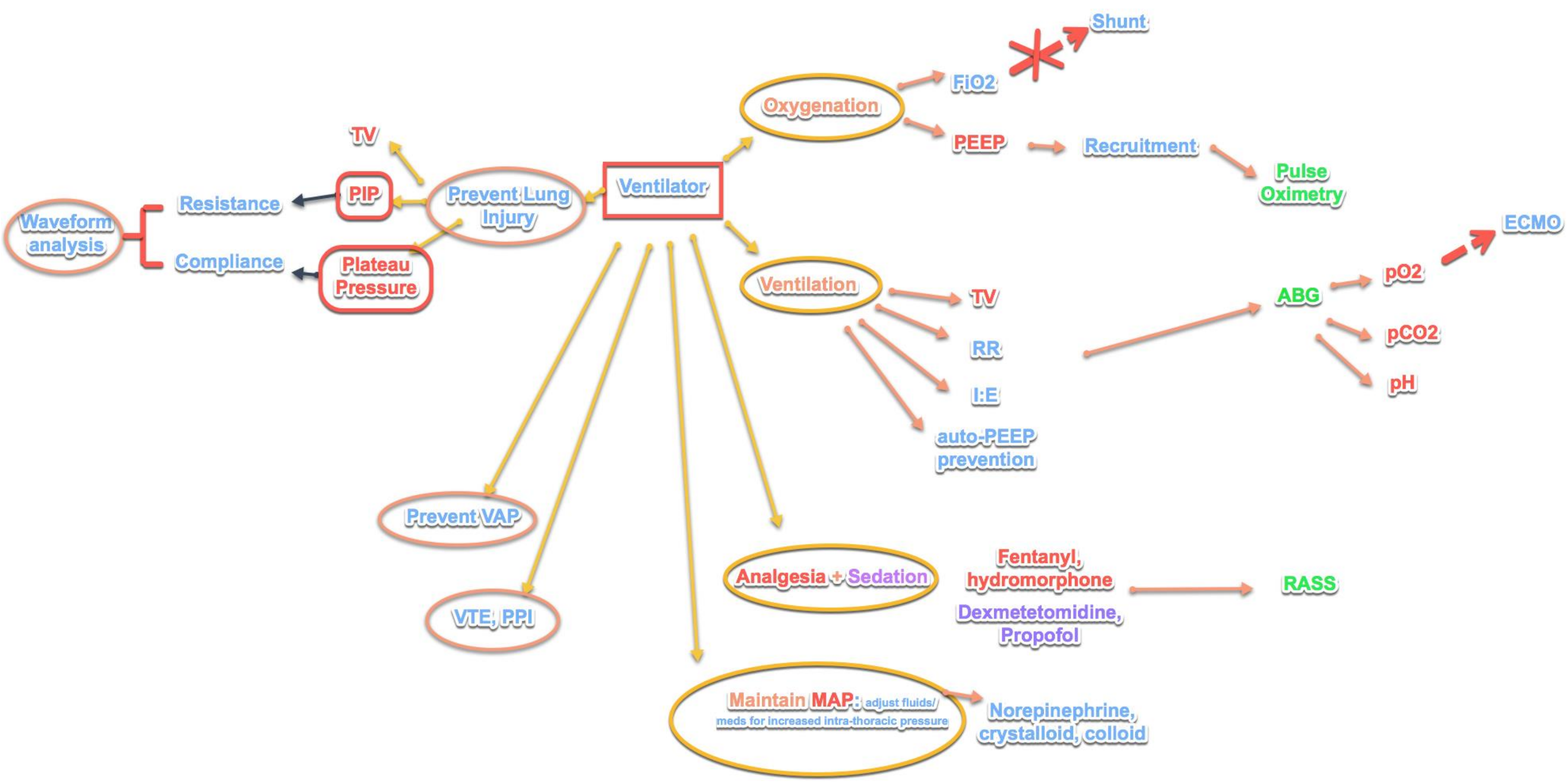
Complexity of Mechanical Ventilation



LUNG INJURY PATHOLOGY PATIENT

Scenario: 60-year-old male. Post-op for 2 days from cardiac surgery. Oxygen saturations have been decreasing steadily with increased work of breathing and shortness of breath.

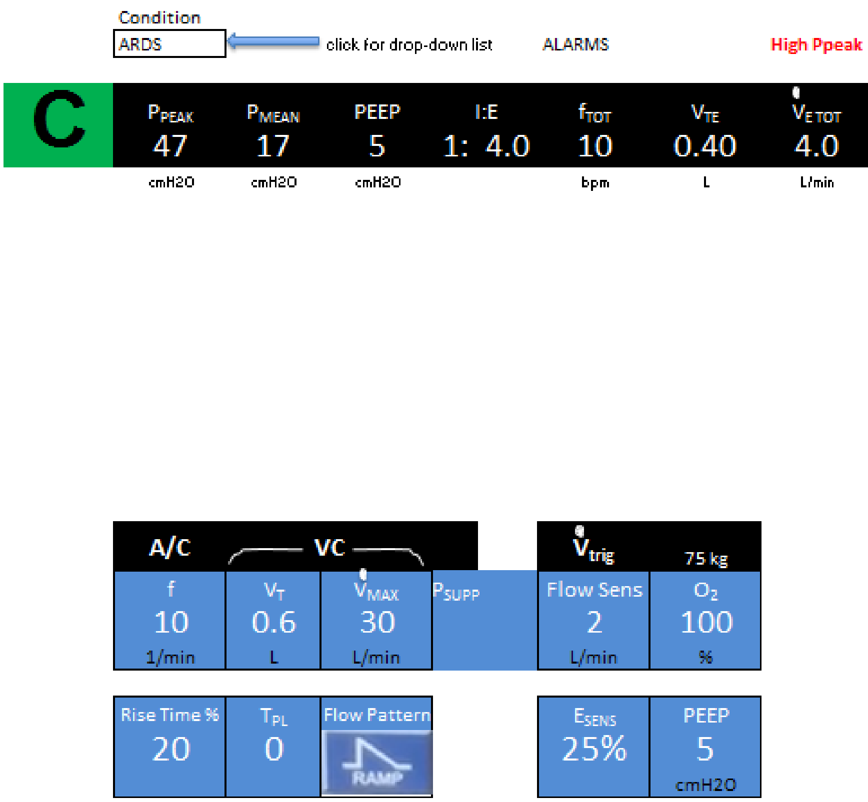
BiPAP trial: FiO_2 100%, IPAP:EPAP = 15/5, **SpO_2: 87%**

98F 110/60 HR 122 RR 24 Weight: 75 kg

Lungs: crackles at bases; no wheezing
Heart: no murmurs

Decide to intubate. Get initial ABG results below and High-Pressure alarm goes off!
You had set High P_{peak} alarm setting to 40.

Scene 1



Current ABG

pH	6.96
pCO_2	95
PaO_2	48
HCO_3	24
SaO_2	76%
BE	-22.0

P_{PLAT}	Cstat
43	16

Issues to consider:

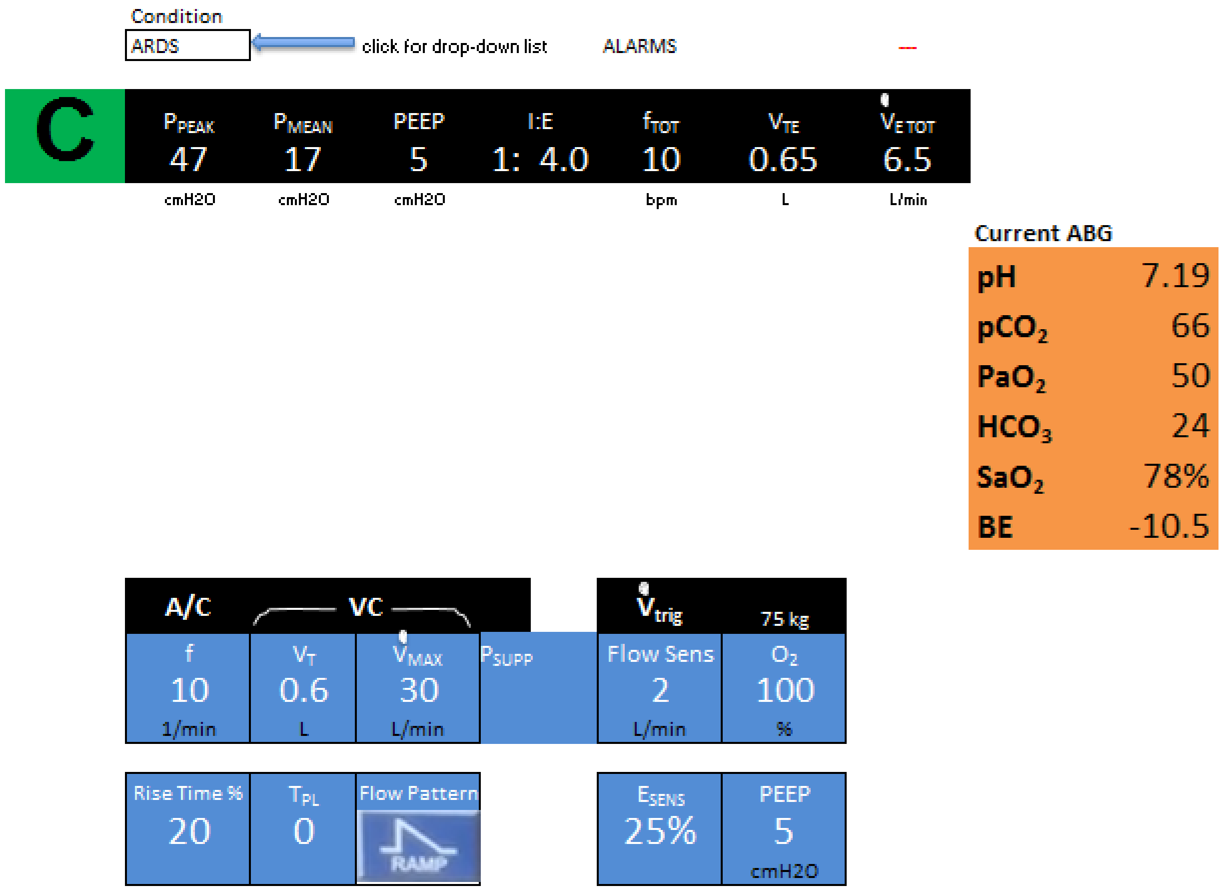
Look at alarm: it's a high peak pressure alarm. 47 is high but not extremely high. Look at your High Alarm setting level. It's currently set to alarm when > 40 cmH_2O. You reset P_{peak} alarm to 55 instead of 40. Alarm now goes away.

Why is Ppeak high? Is pt crashing? What's the BP? What pressures are the alveoli feeling? Check a P_{plat}. Hopefully, it's < 30 cmH_2O.

Simultaneously address HYPOXIA while checking for <u>resistance</u> and <u>compliance</u> issues.

ALWAYS FOCUS ON **OXYGENATION** AND ADEQUATE **BP or MAP**!!

Scene 2



Issues to consider:

HYPOXEMIA/HYPOXIA: **Look at SaO_2 & p_aO_2:** p_aO_2 of 50 & SaO_2 of 78% need fixing! MUST FIX THIS FIRST!

What ventilator settings can correct hypoxemia? FiO_2 & PEEP. But, already at FiO_2 = 100%. . .So, we're left with PEEP. Add 5 more of PEEP to get to a total of PEEP = 10 AND **check a P_{plat}**!

Concerns: the P_{plat} is already dangerously high at 43. Will adding more PEEP increase the P_{plat} further into danger territory—or, will the additional PEEP recruit more alveoli and consequently lower or not change the P_{plat}? Usually want to be careful when titrating PEEP to greater than 15 cm H_2O. Use ARDSNET/FiO_2 tables for lung injury pts (eg, ARDS, pneumonia, acute pulmonary edema) to guide titration of FiO2 and PEEP to maintain SaO_2 > 90%.

Simultaneously check for resistance and compliance issues. Suction prn, bronchodilators prn, check tubing connection/integrity.

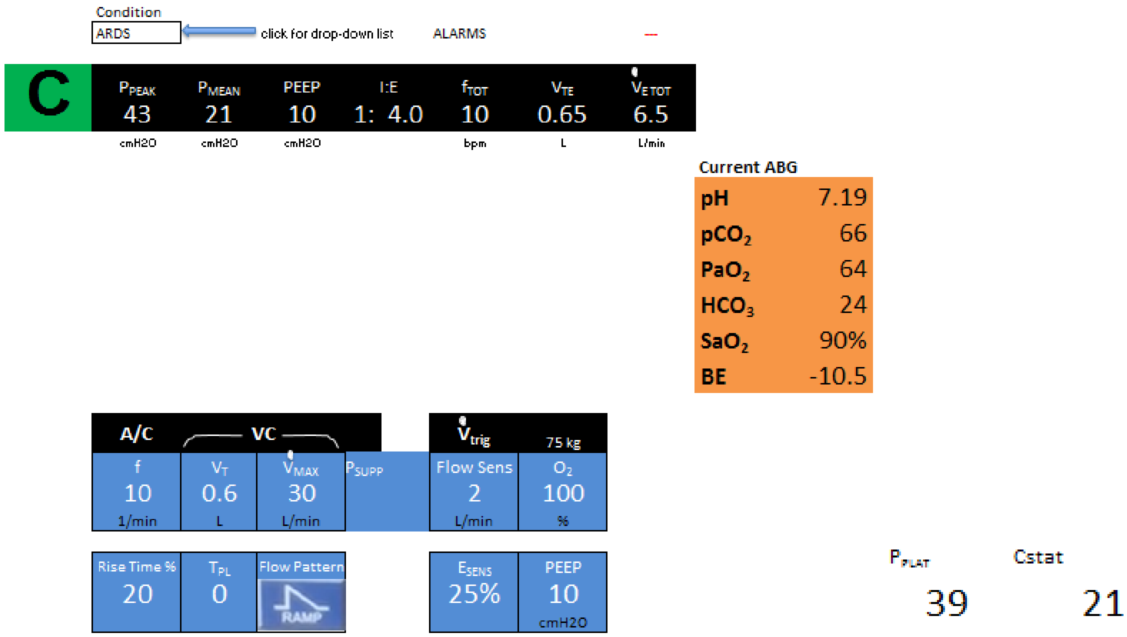
ARDSNET PROTOCOL

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

Scene 3



Issues to consider:

HYPOXEMIA/HYPOXIA: By adding 5 more of PEEP, SaO_2 improved to 90% & the P_{plat} actually decreased (from 43 to 39)—meaning more alveoli were recruited! Always make sure PEEP doesn't drop the venous return, BP or MAP too much! Check BP or MAP. Have IV fluids/vasopressors ready to infuse to correct for hypotension. We have an acute respiratory acidosis. Let's get the pH up a bit.

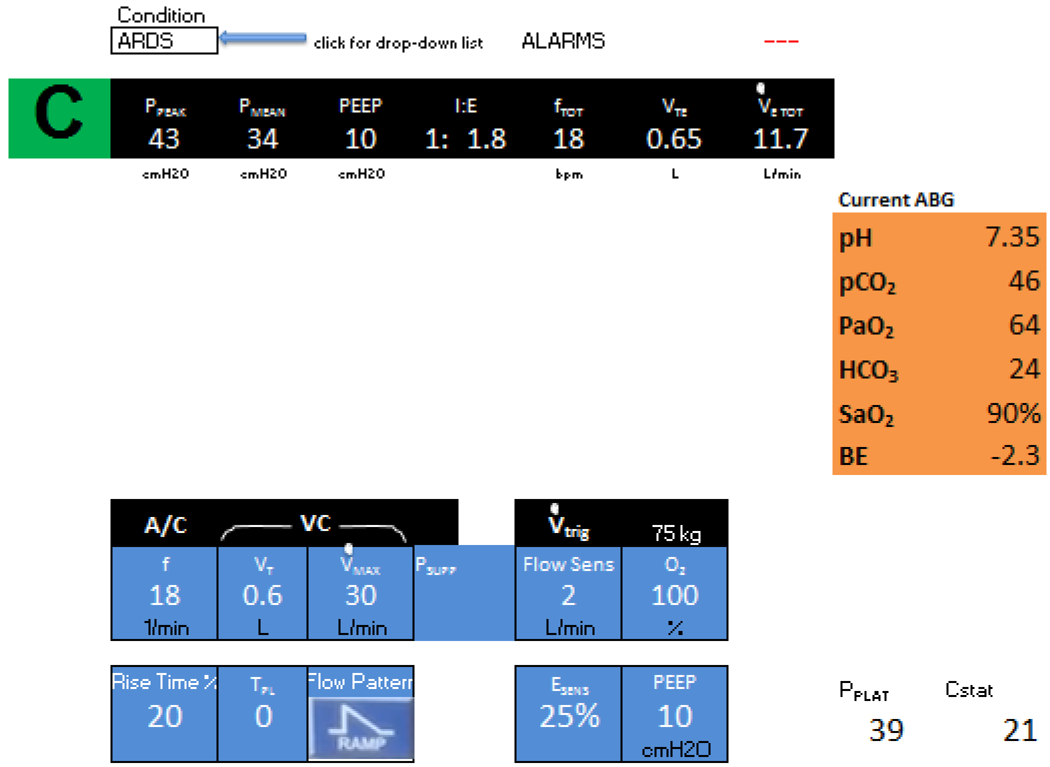
pH is < 7.2. What ventilator settings correct pH? pCO_2 is 66, goal is get to pH > 7.2 by adjusting ventilation/CO_2. ***Should we adjust*** V_T ***or RR 1st?*** Pt is on 8 cc/kg tidal volume. Goal is 6 cc/kg in a pt with non-obstructive lung pathology. So, increase the minute ventilation by **adjusting the RR** (f) to 18.

Keep P_{plat} < 30 cmH_2O!

Concerns: Don't increase V_T (the other variable in minute ventilation) since the P_{plat} is > 30! If you increase V_T, the P_{plat} will likely increase to more dangerous levels & risk *barotrauma—lung injury*.

Simultaneously check for resistance and compliance issues. Suction prn, bronchodilators prn, check tubing connection/integrity.

Scene 4



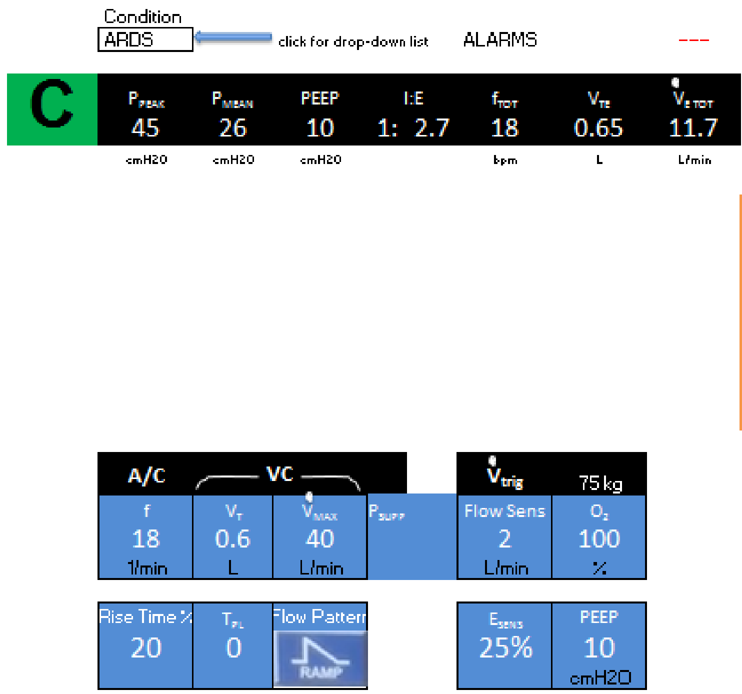
Issues to consider:

Prevent auto-PEEP: the I:E ratio is 1:1.8, which is < 1:2. For non-asthmatic, non-COPD pt, we want I:E to be close to 1:2 to ensure adequate expiratory time to avoid dynamic hyperinflation/auto-PEEP. So, fix by **increasing the $\dot{V}_{max}$** (Inspiratory Flow Rate) to 40 L/min from 30 L/min.

Concerns: significant levels of auto-PEEP causes *barotrauma* and can result in decreased venous return, leading to hypotension & cardiac arrest.

Simultaneously check for resistance and compliance issues. Suction prn, bronchodilators prn, check tubing connection/integrity.

Scene 5



Current ABG

pH	7.35
pCO_2	46
PaO_2	64
HCO_3	24
SaO_2	90%
BE	-2.3

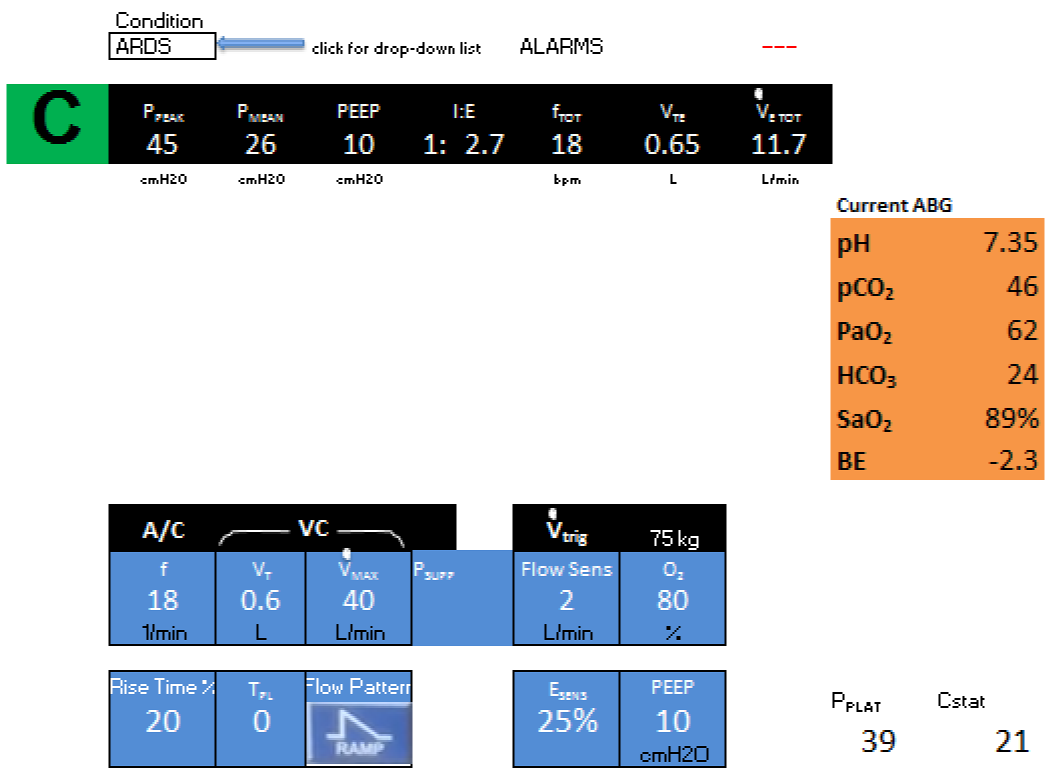
Issues to consider:

Wean FiO_2 from 100%: Now, try to wean the FiO_2 from toxic 100% to 85% & see. Use ARDSNET FiO_2/PEEP table to guide titration if pt is a lung-injury patient and not an obstructive-pattern patient. Try lowering **FiO_2** to 80%.

Concerns: O_2 levels can be toxic to alveoli at levels between 50-100%.

Simultaneously check for resistance and compliance issues. Suction prn, bronchodilators prn, check tubing connection/integrity.

Scene 6



Issues to consider:

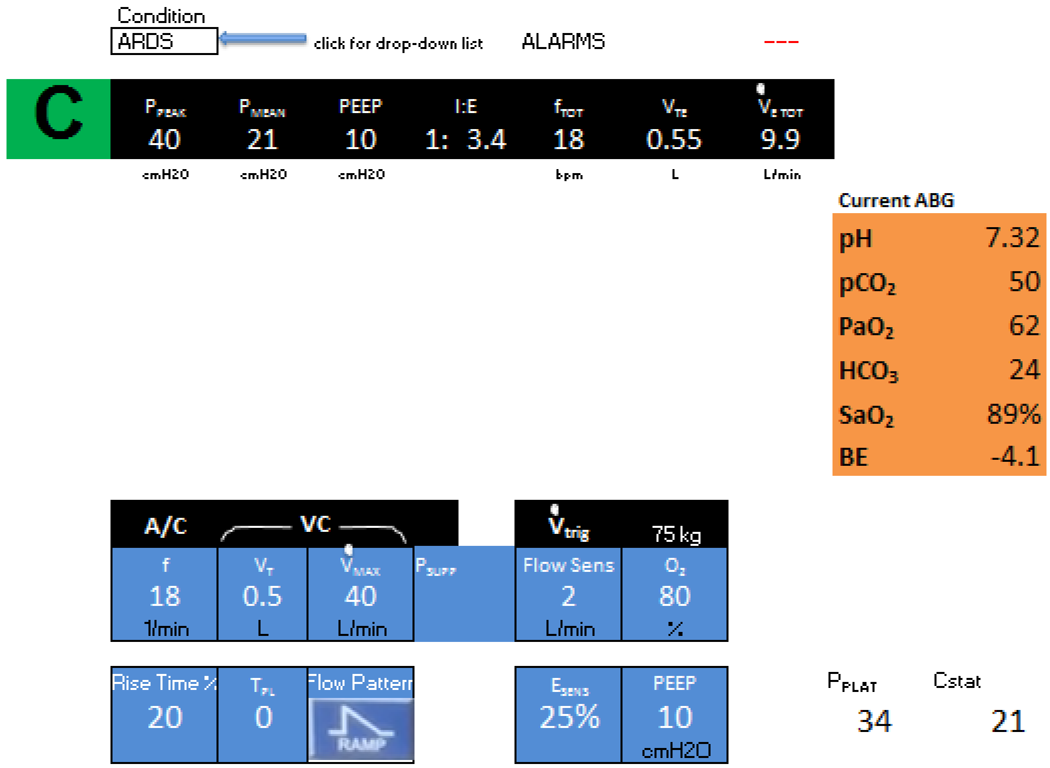
Wean FiO_2 from 100%: at 80% FiO_2, SaO_2 still > 88%--good.

Prevent lung injury: try to get P_{plat} < 35, while maintaining SaO_2 > 88-90%. Only 2 variables affect P_{plat}: V_T & PEEP. Let's lower V_T to ~7cc/kg which is ~ 0.5L. Goal V_T is **6cc/kg IBW** for lung protection strategy.

<u>**Concerns**</u>: Tolerate permissive hypercapnia (pCO_2 50-100 cm H_2O) in order to prevent lung injury. Might need more analgesia/sedation for this→ worry about BP effects of analgesia/sedation.

Simultaneously check for <u>resistance</u> and <u>compliance</u> issues. Suction prn, bronchodilators prn, check tubing connection/integrity.

Scene 7



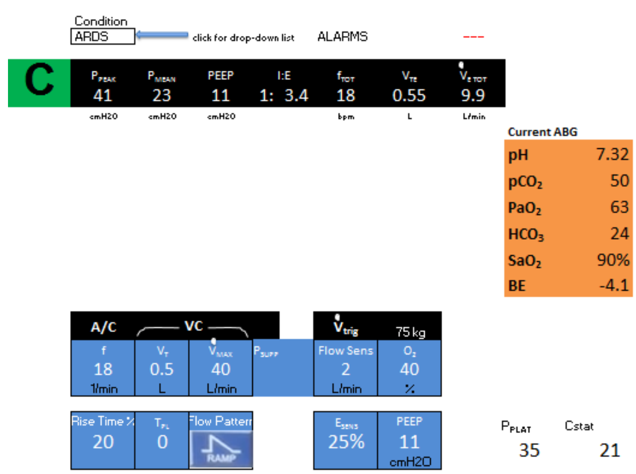
Issues to consider:

Wean FiO2 from 100%: Try FiO_2 of 40% with just enough added PEEP to keep SaO_2 > 88-90%. Here, we needed to dial in 1 more cmH_2O of PEEP. If lung-injury patient, use <u>**ARDSNET protocol**</u> for adjusting FiO_2 & PEEP in tandem. Watch P_{plat}.

Prevent lung injury: Lowering the V_T to 7 cc/kg IBW resulted in a P_{plat} of 34--good. Goals is to get P_{plat} < 35, while maintaining SaO_2 > 88-90%. Goal TV is **6cc/kg IBW** for lung protection strategy. Can go down to V_T of 4 cc/kg IBW—but will require much sedation/analgesia to treat the hypercapnia! Per diagram below, 11 of PEEP at FiO_2 of 40% resulted in P_{plat} of 35.

<u>**Concerns**</u>: delicate balance when adjusting FiO_2 & PEEP to keep P_{plat} < 30-35 cmH_2O.

Simultaneously check for <u>resistance</u> and <u>compliance</u> issues. Suction prn, bronchodilators prn, check tubing connection/integrity.



Scene 8

Issues to consider:

Analgesia: fentanyl, hydromorphone, morphine

Sedation: have IV fluids and vasopressors ready to infuse before giving sedatives.

Neuro/Asthma/COPD: **Propofol** (can drop BP)

Sepsis with tenuous MAP: **dexmedetomidine** (Precedex): can cause bradycardia, hypotension.

Seizures/Alcohol withdrawal/Asthma: **ketamine** (can raise BP), benzos

RASS Scale: +1 to -2

<u>**Concerns**</u>: goal is to prevent delirium by ***not oversedating***. Always ***ensure adequate analgesia***—patient has a hard piece of plastic in his throat after all. Select the best sedative based on clinical issues present.

Richmond Agitation and Sedation Scale (RASS)		
+4	Combative	violent, immediate danger to staff
+3	Very Agitated	Pulls or removes tube(s) or catheter(s); aggressive
+2	Agitated	Frequent non-purposeful movement, fights ventilator
+1	Restless	Anxious, apprehensive but movements not aggressive or vigorous
0	Alert & calm	
-1	Drowsy	Not fully alert, but has sustained awakening to *voice* (eye opening & contact ≥ 10 sec)
-2	Light sedation	Briefly awakens to *voice* (eye opening & contact < 10 sec)
-3	Moderate sedation	Movement or eye-opening to *voice* (but no eye contact)
-4	Deep sedation	No response to voice, but movement or eye opening to *physical* stimulation
-5	Unarousable	No response to *voice or physical* stimulation

OBSTRUCTIVE LUNG PATHOLOGY PATIENT

Scenario: A 33-year-old man is admitted to the ICU after a 6-hour history of worsening asthma symptoms. His medications include albuterol and an inhaled corticosteroid. Despite being treated with IV corticosteroids and high-volume nebulizer with albuterol and ipratropium bromide treatments, he remains symptomatic and can speak only one to two words between breaths. On physical exam, he appears uncomfortable and tired. Temperature is 36.8°C (98.2°F), blood pressure is 150/90 mm Hg, heart rate is 124 beats/min, and respiration rate is 32 breaths/min. Oxygen saturation by pulse oximetry is 92% on 60% oxygen by face mask. Lung examination now reveals a quiet chest where diffuse expiratory wheezes were heard just hours earlier. The patient is unable to perform a peak flow maneuver. Chest x-ray shows hyperinflation and no acute infiltrates. Results of arterial blood gas studies are shown in the table below.

BiPAP trial: FiO_2 100%, IPAP:EPAP = 15/5, **SpO_2: 87%** **Weight: 75 kg** Decide to intubate. Get initial ABG results below and High-Pressure alarm goes off!

Scene 1

ALARMS High Ppeak

C	P_{PEAK}	P_{MEAN}	PEEP	I:E	f_{TOT}	V_{TE}	$\dot{V}_{E\,TOT}$
	47	5	0	1: 9.0	8	0.30	2.4
	cmH2O	cmH2O	cmH2O		bpm	L	L/min

Current ABG

pH	7.05
pCO_2	83
PaO_2	316
HCO_3	24
SaO_2	100%
BE	-17.3

A/C	VC			$\dot{V}_{trig}$	75 kg
f	V_T	$\dot{V}_{MAX}$	P_{SUPP}	Flow Sens	O_2
8	0.5	40		2	100
1/min	L	L/min		L/min	%

Rise Time %	T_{PL}	Flow Pattern	E_{SENS}	PEEP
20	0	RAMP	25%	0
				cmH2O

P_{PLAT}	Cstat
10	49

C	P_{PEAK}	P_{MEAN}	PEEP	I:E	f_{TOT}	V_{TE}	$\dot{V}_{E\ TOT}$
	47	7	0	1: 7.0	10	0.30	3.0
	cmH2O	cmH2O	cmH2O		bpm	L	L/min

had just increased RR to 10 from 8

Current ABG

pH	7.14
pCO_2	72
PaO_2	316
HCO_3	24
SaO_2	100%
BE	-12.8

A/C	VC			$\dot{V}_{trig}$	75 kg
f	V_T	$\dot{V}_{MAX}$	P_{SUPP}	Flow Sens	O_2
10	0.5	40		2	100
1/min	L	L/min		L/min	%

Rise Time %	T_{PL}	Flow Pattern	E_{SENS}	PEEP
20	0	RAMP	25%	0 cmH2O

Condition

Status Asthmaticus click for drop-down list ALARMS **High Ppeak**

C	P	P	PEEP	I:E	f	V	V
	65	6	0	1: 11.0	10	0.30	3.0
	cmH2O	cmH2O	cmH2O		bpm	L	L/min

Current ABG

pH	7.14
pCO_2	72
PaO_2	316
HCO_3	24
SaO_2	100%
BE	-12.8

A/C	VC			$\dot{V}$	75 kg
f	V_T	$\dot{V}_{MAX}$	P_{SUPP}	Flow Sens	O_2
10	0.5	60		2	100
1/min	L	L/min		L/min	%

Rise Time %	T_{PL}	Flow Pattern	E_{SENS}	PEEP
20	0	RAMP	25%	0 cmH2O

P_{PLAT}	Cstat
10	49

C	P_{PEAK}	P_{MEAN}	PEEP	I:E	f_{TOT}	V_{TE}	$\dot{V}_{E\ TOT}$
	47	10	0	1: 4.7	14	0.30	4.2
	cmH2O	cmH2O	cmH2O		bpm	L	L/min

Since MV was low, increased RR to 14.

Current ABG

pH	7.25
pCO_2	59
PaO_2	316
HCO_3	24
SaO_2	100%
BE	-7.6

A/C	VC			$\dot{V}_{trig}$	75 kg
f	V_T	$\dot{V}_{MAX}$	P_{SUPP}	Flow Sens	O_2
14	0.5	40		2	100
1/min	L	L/min		L/min	%

Rise Time %	T_{PL}	Flow Pattern	E_{SENS}	PEEP
20	0	RAMP	25%	0 cmH2O

C	P_{PEAK}	P_{MEAN}	PEEP	I:E	f_{TOT}	V_{TE}	$\dot{V}_{E\,TOT}$
	49	13	0	1: 3.8	14	0.40	5.6
	cmH2O	cmH2O	cmH2O		bpm	L	L/min

By increasing Vt to 0.6, the Ppeak & Pplat increased.

Current ABG

pH	7.31
pCO_2	51
PaO_2	316
HCO_3	24
SaO_2	100%
BE	-4.4

A/C	VC			$\dot{V}_{trig}$	75 kg
f	V_T	$\dot{V}_{MAX}$	P_{SUPP}	Flow Sens	O_2
14	0.6	40		2	100
1/min	L	L/min		L/min	%

Rise Time %	T_{PL}	Flow Pattern	E_{SENS}	PEEP
20	0	RAMP	25%	0
				cmH2O

P_{PLAT}	Cstat
12	49

Issues to consider:

Look at alarm: it's a high peak pressure alarm—expected for an asthma exacerbation with bronchoconstriction. Airway Pressures may be as high as > 70 cmH_2O.

Why is P_{peak} high? Bronchoconstriction. Is pt crashing? What's the BP? What pressures are the alveoli feeling? Check a P_{plat}. Hopefully, it's < 30 cmH_2O.

Simultaneously address any hypoxemia, hypercarbia, BP and goal of ensuring adequate expiratory time. Keep RR on the low side, e.g., 6-10/min. Decrease the i-time by increasing the inspiratory flow rate. Want I:E ~ 1:4 or 1:5 →Must prevent significant auto-PEEP which can decrease venous return. If see significant auto-PEEP, decrease RR & increase V_t. Continuous bronchodilators for at least the 1st hour. IV Mg.

Initial ventilator settings: V_t = 8 cc/kg IBW; FiO_2 100% to start; RR = 10; want I:E to be 1:4 or 1:5.

Calls to action: fix hypoxemia; optimize airway pressures (ie, keep Pplat < 30; PIP < 50; auto-PEEP < 10 – 15) by adjusting RR and V_T and $\dot{V}_{MAX}$; then fix pH via pCO2 by adjusting RR & V_T to maintain adequate MV.

Recognize: increasing $\dot{V}_{MAX}$ can decrease i-time while prolonging e-time. Want I:E to be 1:4 or 1:5.

However, increasing $\dot{V}_{MAX}$ can increase PIP. Keep RR 8-10. May need NMB during 1st few hours to maintain patient-vent synchrony.

Induction agent: ketamine or propofol.

THE HYPERVENTILATORY STATE PATIENT

Scenario: **Fatiguing DKA patient with RR of 30. ABG: 7.0/68/80/13 on 2L NC. You decide to intubate. What ventilator adjustments must be considered after the patient is placed on mechanical ventilation?**

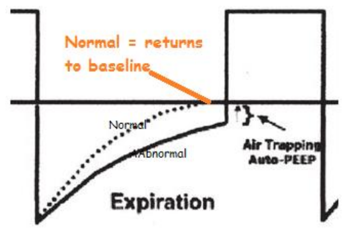
Issues to consider:

Calls to action: Do not forget to adjust ventilator settings to continue the respiratory compensation in an acidotic patient who was hyperventilating to compensate prior to your placing him on mechanical ventilation! That is, ensure RR is high enough to continue blowing off CO_2 to raise his pH. Target his pCO_2 to be near 20 mmHg as appropriate compensation for his severe metabolic acidosis.

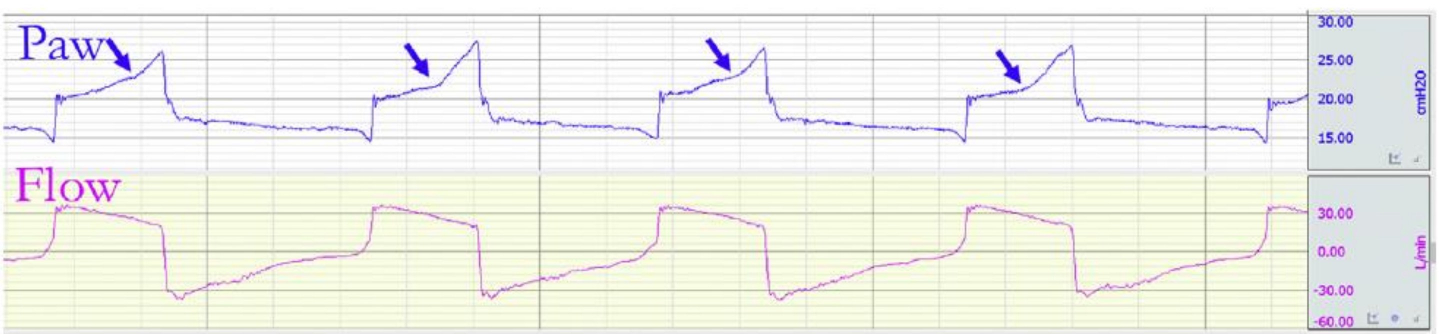
Initial ventilator settings: V_t = 8 cc/kg IBW; FiO_2 100% to start; RR = 30.

Some common things you can do after stabilizing patient: preventing delirium by checking for other things that can cause patient-ventilator dyssynchrony

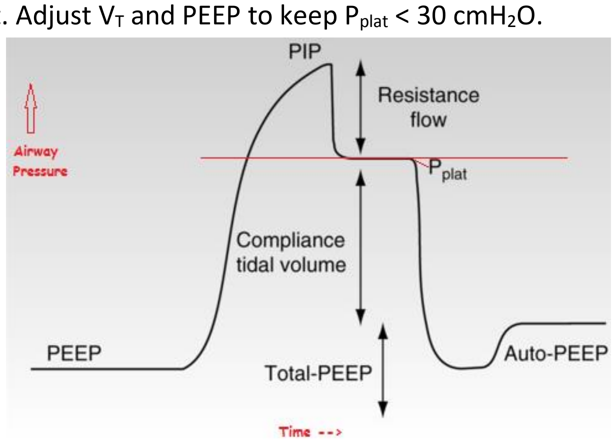
1. **Auto-PEEP**: If Peak Pressures (P_{peak}) start to rise, look at **Flow-Time waveform** to check for $PEEP_i$ or auto-PEEP. Adjust by *decreasing the RR or f to allow more Expiratory time—usually ~ 10 breaths per minute to start with*. For asthmatics/COPD patients, target an I:E ratio to 1:4 or 1:5. For other patients, target 1:2.



2. **Flow Starvation**: Look at **Pressure-Time waveform** to check for relative airflow starvation (will see concave deflection during inspiration phase). Adjust by changing $\dot{V}_{max}$, or "Peak Flow" or "Inspiratory Flow Rate."



3. **Plateau Pressures**: check the plateau pressure if Peak pressure starts to rise. Perform this 0.2-0.4 second inspiratory-hold measurement. Adjust V_T and PEEP to keep $P_{plat} < 30$ cmH_2O.



ALARM ALARM ALARM!!!!!

BP is 40/20! High-Pressure alarm is sounding. . .

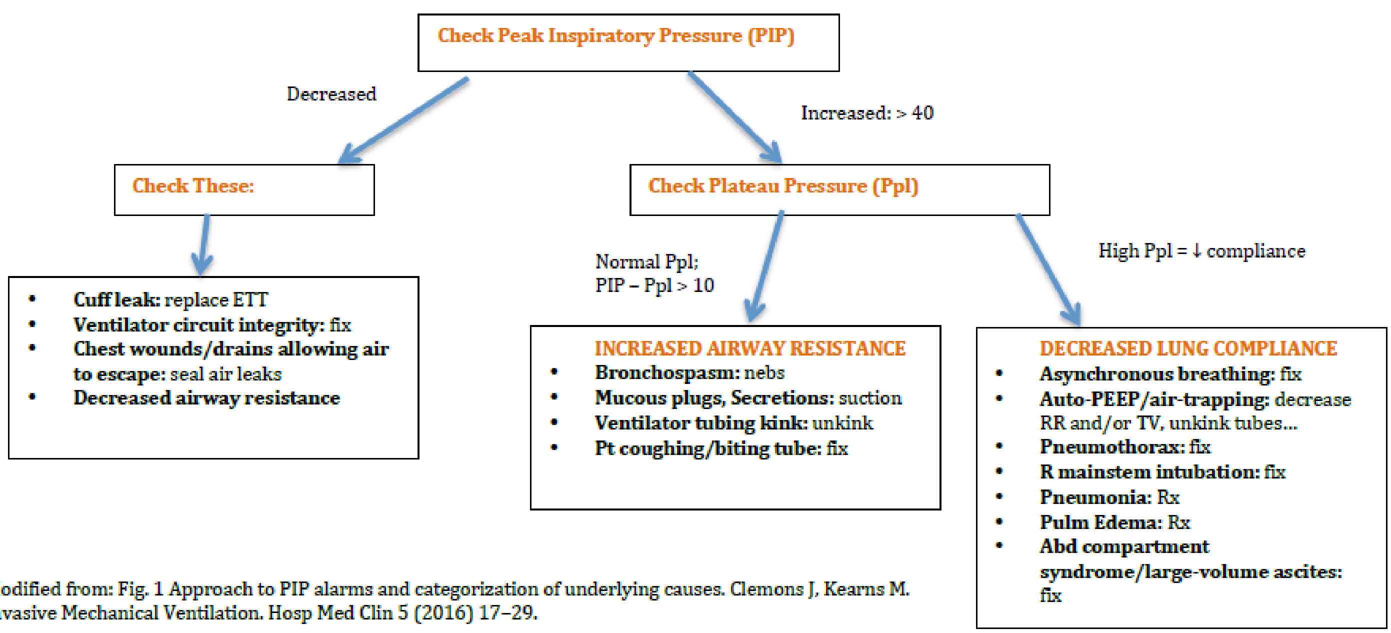
1st move?

Disconnect the Y-connector from the patient's ET tube (but, leave the ET tube in place!) & wait for any air to rush out of the patient (from auto-PEEP); if no air is heard rushing out of the patient, manually bag the patient to see if bagging is easy. If patient bags easily, the alarms are likely due to a ventilator issue or fluid in the ventilator tubing or kinking of the tubing.

Next. . .

- Check $ETCO_2$ to ensure that the ETT is still in proper position.
- Apply suction catheter to suck out any mucous/mucous plugs.
- Check for pneumothorax (lung exam, use U/S if available, CXR).
- Check for tube kinking anywhere in the circuit.
- If low pressure alarm, check for any tube disconnections; check endotracheal tube cuff pressure (should be 20-25 cmH_2O).
- If elevated peak pressures are seen, check P_{plat} to see if there is a compliance or resistance issue.
- Start albuterol nebulizers/bronchodilators if suspect bronchoconstriction. Listen for wheezing.
- Check CXR for worsening ARDS, pulmonary edema, etc.

DISCONNECT VENTILATOR FROM ET TUBE IF PT IS CRASHING



Modified from: Fig. 1 Approach to PIP alarms and categorization of underlying causes. Clemons J, Kearns M. Invasive Mechanical Ventilation. Hosp Med Clin 5 (2016) 17–29.

PEARLS & TAKE-HOME POINTS

- For obstructive pathology patients (eg, asthma, COPD):
  - **Adjust RR 1st** when dealing with pCO_2 issues. Beware if you decide to consider adjusting T_V first to increase minute ventilation.
  - **prevent** significant **auto-PEEP** -- usually by fine tuning the RR. Check Flow-Time waveform.
  - Get **I:E ratio** close to 1:4 or 1:5 -- usually by fine tuning the RR setting and the Peak Flow(Inspiratory Flow Rate)
- For lung injury pathology patients (eg, ARDS, pneumonia, pancreatitis, acute pulmonary edema, trauma, etc.):
  - prevent volu-/baro-/atelectrauma -- **Keep P_{plat} < 30** cmH_2O by using **low V_T strategy** of 6cc/kg.
  - usually will want to adjust T_V 1st when dealing with P_{plat} elevations.
- For hyperventilatory state pathology patients (eg, severe metabolic acidosis/DKA):
  - **Give them back their respiratory compensation** while on the ventilator—usually with the RR setting.
- Known COPD: target patient's baseline pCO_2 with goal of adjusting pCO_2 to get to a pH > 7.1.
- An exhaled tidal volume much lower than the set tidal volume =
  - a loss of ventilator-circuit integrity or an air leak around the endotracheal tube
  - an inadequate expiratory time due to obstructive lung disease or ventilator-patient asynchrony.
- An exhaled tidal volume higher than the set tidal volume = may be effect of large cardiogenic oscillation. Cardiogenic oscillations are fluctuations in ventilator airway pressure, flow, and potentially volume waveforms in phase with the cardiac cycle.

$$R_{peak} = (PIP - P_{plat})/(\dot{V}_{max}\ (\text{in LPM})/60)$$

$$P_{plat} = PEEP + V_T/C_{stat}$$

$$C_{stat} = V_T\ (\text{in mL})/(P_{plat} - PEEP) \qquad C_{dyn} = V_T\ (\text{in mL})/(PIP - PEEP)$$

$$\text{Peak Pressure (inspiratory)} = PIP = P_{plat} + [R_{peak} \times (\dot{V}_{max}/60)]$$

$$P_{mean} = PEEP + [PIP/(iTime + eTime)]$$

$$V_T\ (\text{in L})/iTime = \dot{V}_{max}\ (\text{in LPM})/60$$

$$iTime = \text{inspiratory pause} + (V_T\ (\text{in L}) \times 60)/\dot{V}_{max}(\text{in LPM})$$

$$eTime = [(60/RR) - iTime)]/iTime$$

Driving Pressure: $P_{plat} - PEEP$

Abbreviations:

R_{peak} = peak resistance

V_T = tidal volume

RR = respiratory rate

P_{plat} = plateau pressure

PIP = peak inspiratory pressure

iTime = inspiratory time

eTime = expiratory time

$\dot{V}_{max}$ = inspiratory flow rate (liters per minute) or peak inspiratory flow or "peak flow"

C_{dyn} = dynamic compliance

C_{stat} = static compliance

References

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