Ventilator 101

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Original power point made by John Meyers, MD with special thanks to the "Dominating the Vent" EMCrit podcast by Scott Weingart, MD

Lecture Outline

- Discuss basic respiratory physiology
- Discuss basics of ventilator settings
- Discuss ED applicable pathophysiology
- Discuss algorithm for ED ventilator management

The very basics:

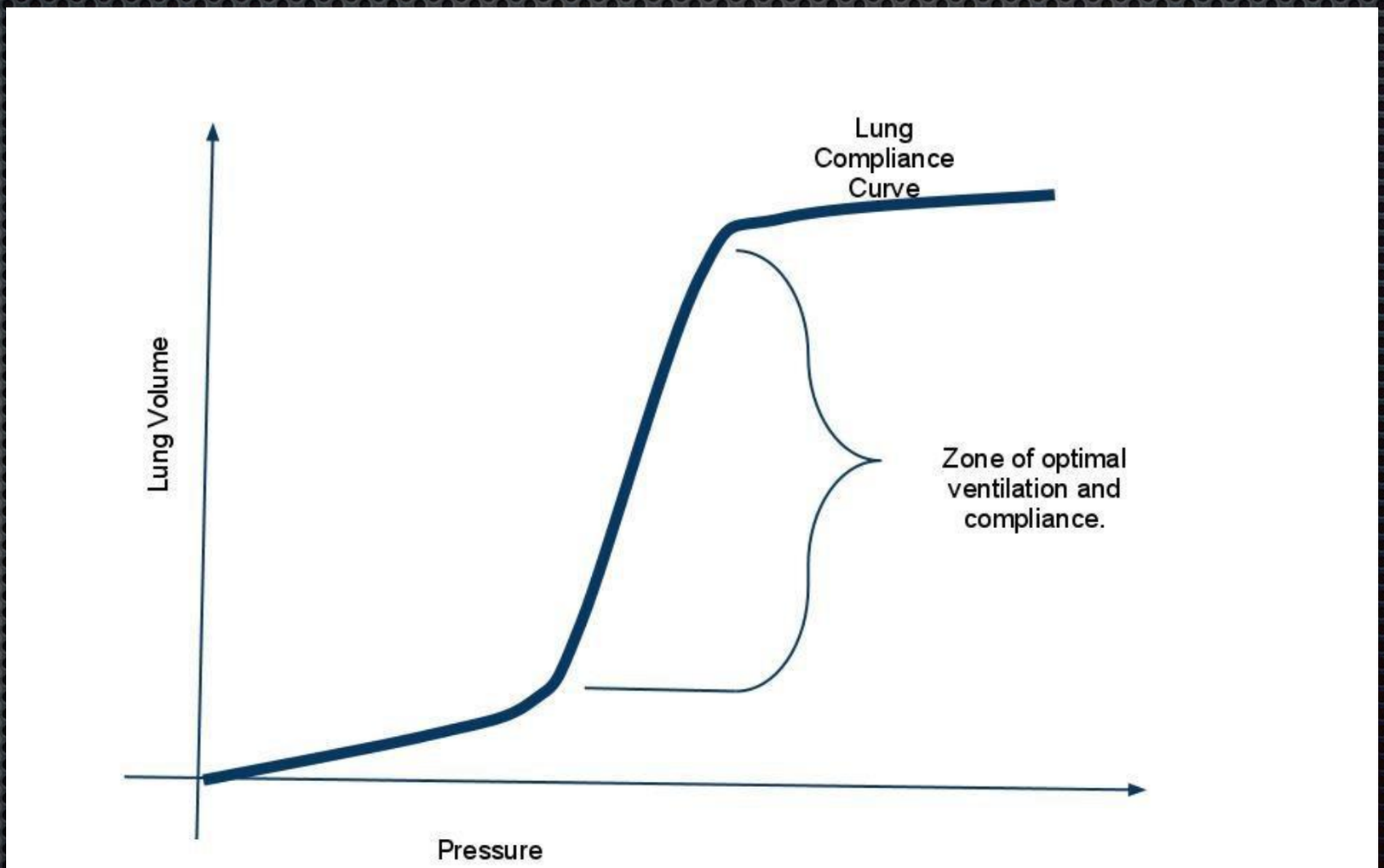
- Lungs do two important things:
  - Ventilation (Blowing off CO2)
  - Oxygenation (Transfer of O2 from the air, through alveoli, to blood)

The lungs use a negative pressure ventilation strategy: the diaphragm contracts to enlarge the chest cavity.

Mechanical ventilation is Positive Pressure Ventilation (PPV). Air is forced in to inflate the lungs. The mechanics are different.

Basic Terminology:

- Compliance - change in volume with a given change in pressure



Compliance = Change in volume/ Change in pressure

More terminology

- Tidal Volume: Volume of air in a given breath
- Minute Ventilation: Breaths/Min x Tidal Volume
- Resistance - pressure divided by flow
  - Fixed resistance of tubing + variable resistance of lung and airways
- Dead Space - portion of each breath that doesn't contribute to gas exchange in the lungs
- Tubing contributes dramatically to dead space, and effectively doubles the required minute ventilation

Indications for intubation and mechanical ventilation:

- Airway protection
- Hypoxic Respiratory failure: PO2 < 50 on 100% NRB, V/Q mismatch
  - Not Oxygenating
- Hypercarbaric respiratory failure: PH < 7.3 or PCO2 >50
  - Not Ventilating

Well?

- So, are you oxygenating? Are you ventilating? Are you protecting your airway?

- No to one (or more) of those three?
  - OK, you've visualized tube passing through cords, you've got your bilateral breath sounds, you see condensation in the tube, EtCO2 looks great, getting ready to order an ABG and chest xray, but first... vent management:

"What settings do you want Dr.?"

- For the sake of ED ventilator management, we can simplify our approach to two general strategies:
  - Lung Injury strategy
  - Obstructive strategy

- Those that are being intubated purely for airway protection can BECOME part of the "lung injury" category if vent settings are poorly chosen, and ARDSnet studies show that lung protective strategies provide a mortality benefit regardless (we'll get into this in a bit...)
- So, for sake of simplicity, we will have only 2 management strategies.

But first:

- Dangers of PPV
  - Increased intrathoracic pressure (which can lead to decreased venous return)
  - Increased ICP (maybe)
  - Pulmonary volutrauma and atelectotrauma
  - Mismanagement

- More chronic concerns/dangers:
  - Gastric ulcers, muscle atrophy, infection/contamination
    - We can let our friends in the ICU manage these issues.

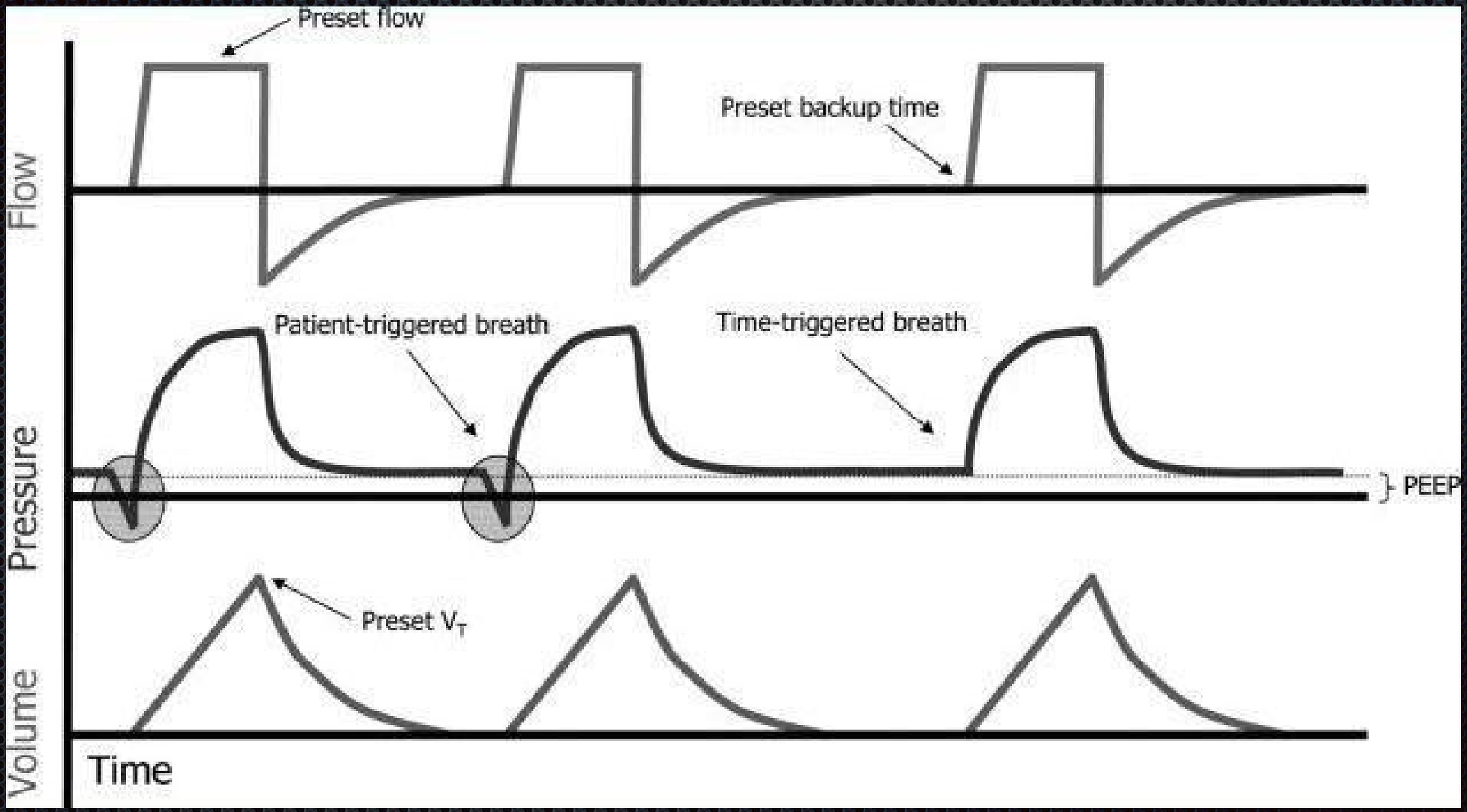
Ventilator Mode:

A few more basics before diving into Lung Injury strategy:

- Assist Control:
  - Gives predetermined volume and rate.
  - Patient may "trigger" breath with an inhalation, resulting in preset volume being given

- Control breaths - machine determined
- Assist breaths - patient determined

Assist Control:



Talk the talk:

- Vent setting nomenclature

12 bpm /500ml /100% /5cm-H2O
RR /Tidal Volume /FiO2 /PEEP

The “lung injured” pathway:

- OK, so we have our “lung injured patient". We're thinking diagnoses along the lines of:
  - Pneumonia
  - Pulmonary Edema
  - Pulmonary Contusion
  - ARDS
  - Airway protection (GCS <8, status epilepticus, intoxication/ingestion, brain bleed, whatever)
  - We don't know

- But NOT obstructive pathology like asthma, or COPD

- Following the ARDSNet study: The first choice we will make is ventilator mode. We've skipped a lot of the modes because they are out of the scope of this lecture. Let's go with assist control.

Pick a volume!

- ARDSnet: Big critical care study group showed that lower volumes resulted in better mortality, with less lung trauma.
- Why do lung injured patients do better with lower volume?

Injured lungs are small lungs!

ARDSNet Volume recommendations

- They found that a Tidal Volume between 6-8 ml/kg of IDEAL BODY WEIGHT resulted in the best outcomes.
  - Research has shown that this was the case when there was no lung injury.

- This is a way of saying that a patients HEIGHT decides their tidal volume.

Ideal body weight calculations

- Calculate Ideal Body Weight (IBW)
  - Males = 50 + 2.3 [height (inches) - 60]
  - Females = 45.5 + 2.3 [height (inches) -60]

- Start at 8mL/kg tidal volume

Or use a handy graph...

HEIGHT	PBW	4 ml	5 ml	6 ml	7 ml	8 ml
4' 0" (48)	17.9	72	90	107	125	143
4' 1" (49)	20.2	81	101	121	141	162
4' 2" (50)	22.5	90	113	135	158	180
4' 3" (51)	24.8	99	124	149	174	198
4' 4" (52)	27.1	108	136	163	190	217
4' 5" (53)	29.4	118	147	176	206	235
4' 6" (54)	31.7	127	159	190	222	254
4' 7" (55)	34	136	170	204	238	272
4' 8" (56)	36.3	145	182	218	254	290
4' 9" (57)	38.6	154	193	232	270	309
4' 10" (58)	40.9	164	205	245	286	327
4' 11" (59)	43.2	173	216	259	302	346
5' 0" (60)	45.5	182	228	273	319	364
5' 1" (61)	47.8	191	239	287	335	382
5' 2" (62)	50.1	200	251	301	351	401
5' 3" (63)	52.4	210	262	314	367	419
5' 4" (64)	54.7	219	274	328	383	438
5' 5" (65)	57	228	285	342	399	456
5' 6" (66)	59.3	237	297	356	415	474
5' 7" (67)	61.6	246	308	370	431	493
5' 8" (68)	63.9	256	320	383	447	511
5' 9" (69)	66.2	265	331	397	463	530
5' 10" (70)	68.5	274	343	411	480	548
5' 11" (71)	70.8	283	354	425	496	566
6' 0" (72)	73.1	292	366	439	512	585
6' 1" (73)	75.4	302	377	452	528	603
6' 2" (74)	77.7	311	389	466	544	622
6' 3" (75)	80	320	400	480	560	640
6' 4" (76)	82.3	329	412	494	576	658
6' 5" (77)	84.6	338	423	508	592	677
6' 6" (78)	86.9	348	435	521	608	695
6' 7" (79)	89.2	357	446	535	624	714
6' 8" (80)	91.5	366	458	549	641	732
6' 9" (81)	93.8	375	469	563	657	750
6' 10" (82)	96.1	384	481	577	673	769
6' 11" (83)	98.4	394	492	590	689	787
7' 0" (84)	100.7	403	504	604	705	806

PBW and Tidal Volume for Females

ARDSNet Studies

HEIGHT	PBW	4 ml	5 ml	6 ml	7 ml	8 ml
4' 0" (48)	22.4	90	112	134	157	179
4' 1" (49)	24.7	99	124	148	173	198
4' 2" (50)	27	108	135	162	189	216
4' 3" (51)	29.3	117	147	176	205	234
4' 4" (52)	31.6	126	158	190	221	253
4' 5" (53)	33.9	136	170	203	237	271
4' 6" (54)	36.2	145	181	217	253	290
4' 7" (55)	38.5	154	193	231	270	308
4' 8" (56)	40.8	163	204	245	286	326
4' 9" (57)	43.1	172	216	259	302	345
4' 10" (58)	45.4	182	227	272	318	363
4' 11" (59)	47.7	191	239	286	334	382
5' 0" (60)	50	200	250	300	350	400
5' 1" (61)	52.3	209	262	314	366	418
5' 2" (62)	54.6	218	273	328	382	437
5' 3" (63)	56.9	228	285	341	398	455
5' 4" (64)	59.2	237	296	355	414	474
5' 5" (65)	61.5	246	308	369	431	492
5' 6" (66)	63.8	255	319	383	447	510
5' 7" (67)	66.1	264	331	397	463	529
5' 8" (68)	68.4	274	342	410	479	547
5' 9" (69)	70.7	283	354	424	495	566
5' 10" (70)	73	292	365	438	511	584
5' 11" (71)	75.3	301	377	452	527	602
6' 0" (72)	77.6	310	388	466	543	621
6' 1" (73)	79.9	320	400	479	559	639
6' 2" (74)	82.2	329	411	493	575	658
6' 3" (75)	84.5	338	423	507	592	676
6' 4" (76)	86.8	347	434	521	608	694
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6' 7" (79)	93.7	375	469	562	656	750
6' 8" (80)	96	384	480	576	672	768
6' 9" (81)	98.3	393	492	590	688	786
6' 10" (82)	100.6	402	503	604	704	805
6' 11" (83)	102.9	412	515	617	720	823
7' 0" (84)	105.2	421	526	631	736	842

PBW and Tidal Volume for Males

ARDSNet Studies

Minute Ventilation

- Next step is choosing your rate.
- Rate = Ventilation. Don't use Tidal Volume to adjust ventilation!
- At rest, you require about 60cc/kg/min
- When you are intubated, that requirement increases due to dead space in the tubing, as well as the hypermetabolic state that is causing you to be intubated (infection, seizure, etc.)
- 70kg * 120cc/kg/min = 8400 cc/min = minute ventilation
- So, with our 8mL/kg tidal volume of 560mL… we need about 15 breaths/min to reach that minute ventilation

  560 mL * 15bpm = 8400 ml/min

  In general, you can start at 16-18 BPM

FiO2/PEEP:

- 5 minutes at 100% to resolve any peri-intubation hypoxia.
- Drop FiO2 to 40% while watching the patient.
- Raise FiO2/PEEP to >90% saturation and less than 95%
  - Hyperoxia is damaging! Increasing literature to prove this.

ARDSNet Peep/FiO2 table

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

Why PEEP?

- Avoiding Atelectotrauma
  - As alveoli collapse, the inherent cohesive forces of the fluid therein tend to hold the alveoli in collapsed state
  - Re-opening the alveoli requires more force
  - The perpetual opening/closing shearing force results in inflammatory cascades, and lung damage
  - PEEP keeps atelectasis at bay!
  - Stop de-recruitment of your alveoli with PEEP!

Why not PEEP?

- Slight decrease in pre-load
  - Give your patients a little more fluid

- The idea that PEEP can cause pneumothorax = false! ARDSNet did study on much higher peep, values as high as 24 cm-h2O.
  - No pneumothoraces. But also no improvement in mortality over the lower PEEP settings.

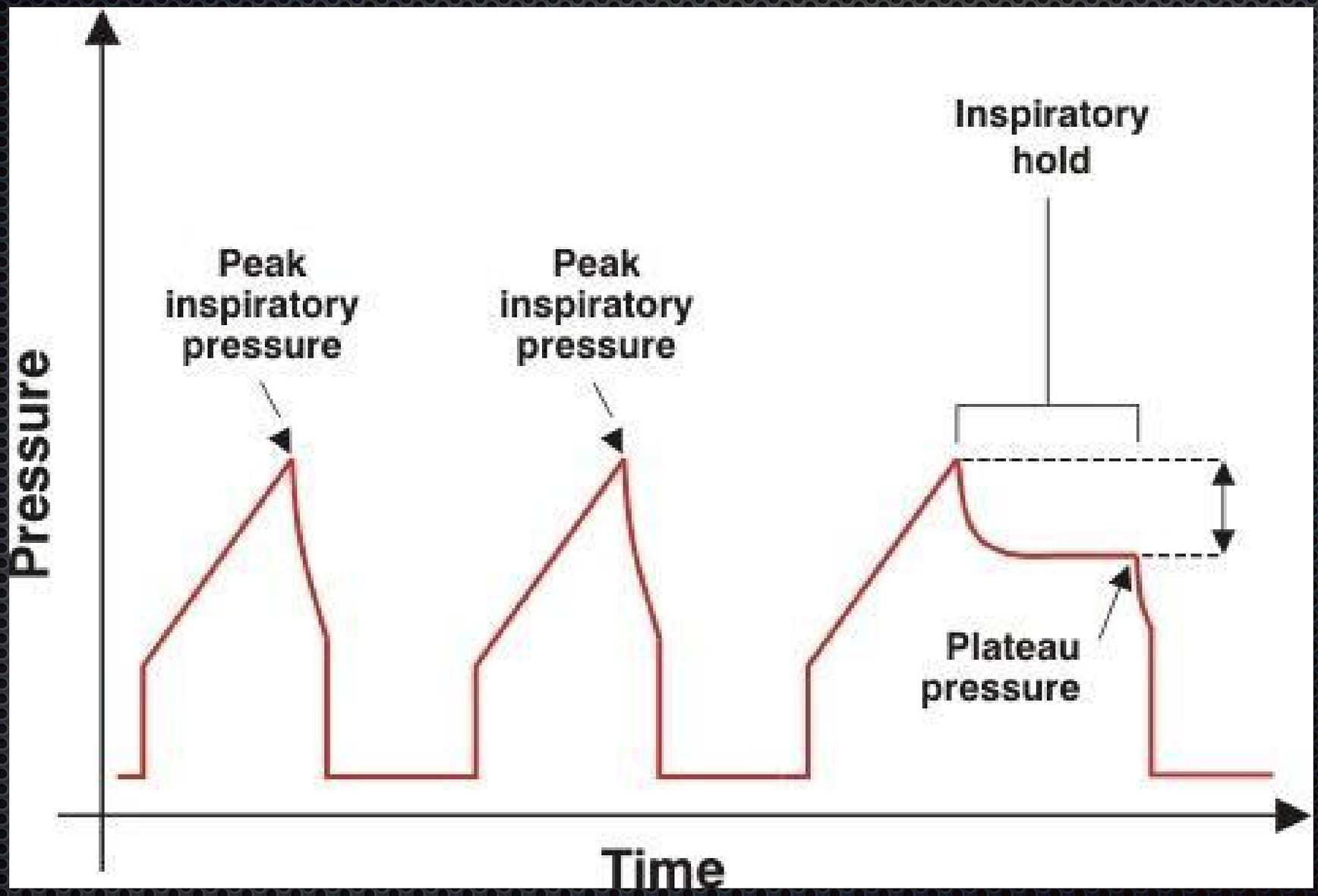
The last setting:

- Inspiratory flow rate
  - Start high. 60-80 LPM.
  - Primarily for patient comfort
  - In Lung Injury pathway, this setting is relatively unimportant.
  - Primarily for patient comfort (usually patients appear more comfortable with higher setting)

How's that volume setting treating you?

- ARDSNet states 6-8ml/kg. We start at 8.
- Once your patient has been ventilated for ~30 minutes or so, presumably all your alveoli are recruited.
- At this point, check a Plateau Pressure.
  - This is a measure of possible barotrauma.
  - Drop your Tidal volume until plateau pressure is less than 30.

Plateau Pressure

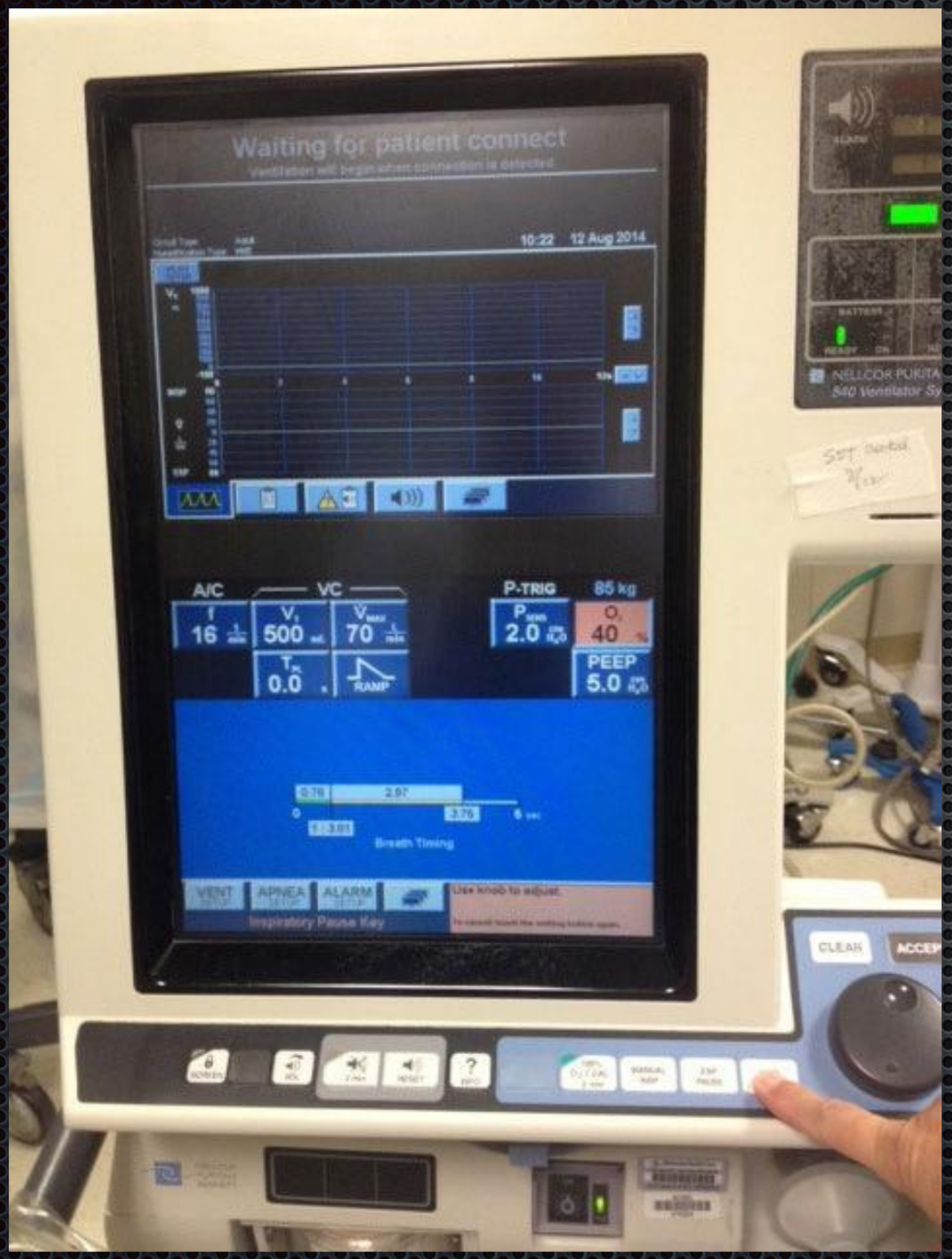


Peak vs. plateau pressures

- Peak = airway resistance
- Plateau = overall elastic resistance/compliance of lung

- High Peak, Normal Plateau: kink in tube, patient biting ETT, Mucous Plug , R mainstem bronchus intubation, asthma, COPD.
- High Peak, High Plateau: pulmonary edema, pneumonia, ARDS, hemorrhage

Inspiratory Pause = Plateau Pressure



Inspiratory Hold

Lung Injury Pathway Summary:

- Assist Control
- Guesstimate 8ml/kg based on height
- Set a rate of 16-18 with FiO2 of 100% and PEEP of 5.
- Drop FiO2 to 40%
- Increase PEEP/FiO2 based upon ARDSNet Table to 90-95% saturation.
- Set IFR high (60-80). If you remember.
- Check Plateau pressure, adjust volume down to 6mL/kg or until <30 cm-H2O

Obstructive Strategy:

- The pathophysiology of obstructive lung disease is very different.
- Accordingly, ventilator management is very different.
- Our primary battle to be fought is exhalation.
  - The way to win this battle is to buy TIME!
  - Start with Assist Control, and 8ml/kg tidal volume, just as in the lung injury strategy.

How do I buy time?

- Lower your respiratory rate, and increase the inspiratory flow rate!
- First set your Inspiratory Flow Rate to 80-100 LPM. This buys a small amount of time.
  - @ rate of 60, 500 mL enters the lungs in .5 seconds
  - @ rate of 100, 500mL takes 0.3 seconds

Respiratory Rate and I:E

- Slow! Low! Start at 8-10 BPM
- Permissive hypercapnea is OK
  - Keep PH >7.2
- You want an I:E of 1:4-1:5
  - All about buying TIME!

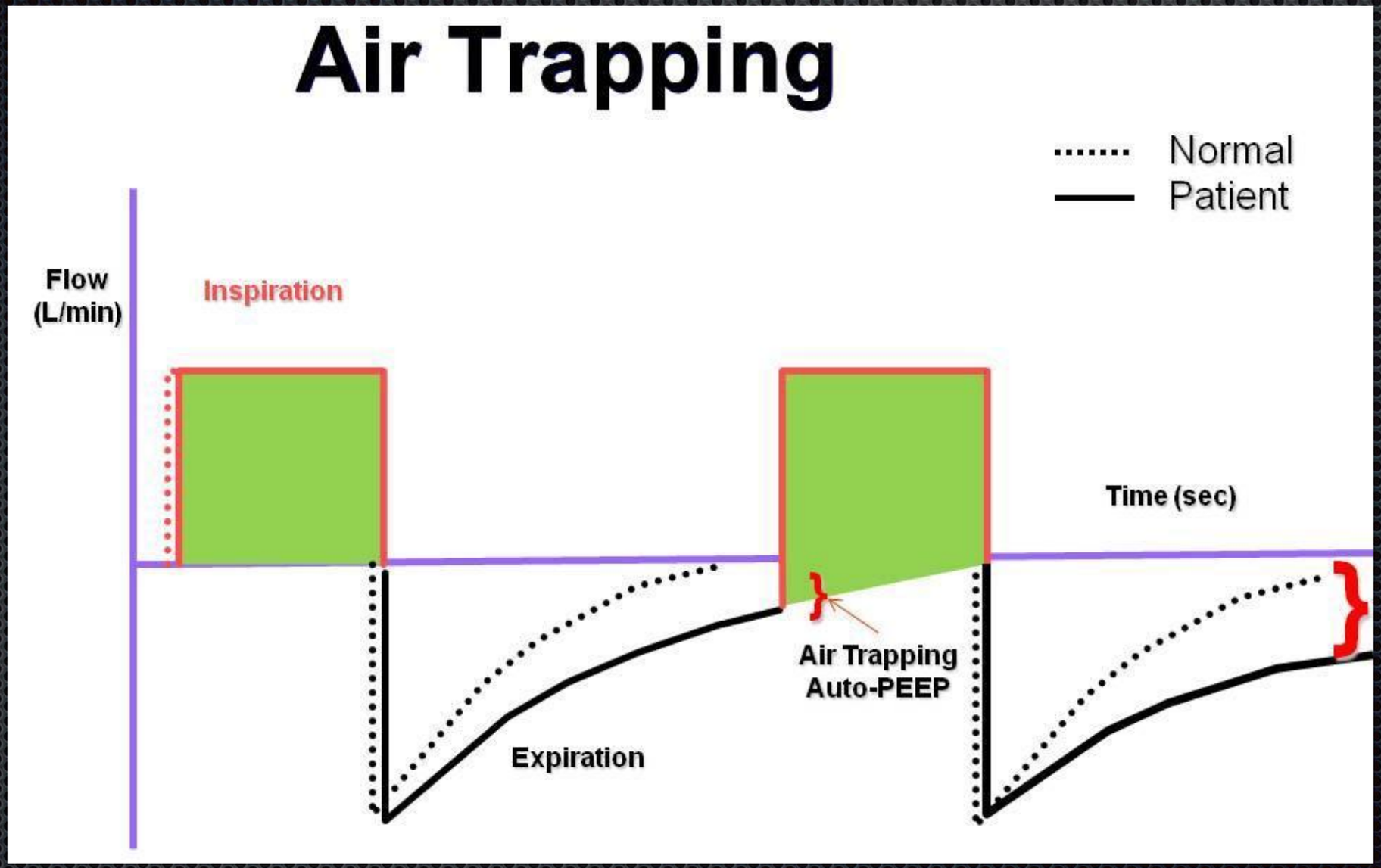
PEEP and FiO2

- In obstructive lung pathology, there is essentially auto-PEEP. A hyperinflated state.
  - Set PEEP to ZERO. Also known as ZEEP.
  - Titrate FiO2 to increase your sats to >90 and <95%
  - Oxygen requirements generally not that high on pure obstructive patients.
    - Disease of ventilatory failure. Not of oxygenation failure.

Auto PEEP

- What is auto PEEP?
  - If expiratory flow is not yet zero at the start of a new breath, you are perpetually pushing more and more volume of air into the lungs.
- Auto PEEP is bad
  - Pressure slowly rises, and rises, and rises until… pneumothorax, “lung tamponade” due to increasing intrathoracic pressure, barotrauma.

Auto PEEP


Air Trapping
Normal
Patient
Flow (L/min)
Inspiration
Time (sec)
Air Trapping
Auto-PEEP
Expiration

Plateau Pressure…. again

- If <30, they don’t have significant auto-PEEP.
- Measure this every half hour or so. To make sure they aren’t getting worse.

I have auto PEEP!?

- My waveform shows me that the patient is still exhaling when a new breath starts.
- My plateau pressure is >30.
- What do I do?!
  - Lower respiratory rate! Buy TIME!

Doctor Doctor!

. You are talking to the hospitalist. You've paged them four times. While endorsing the first of four admissions, the nurse comes up to you and tells you that your patient doesn't look so good.

. BP is 60/40. Saturation is in the 60's.

What do I do?

- Listen to breath sounds?
- US to look for Pneumothorax?
- Adjust the vent?
- Order CXR to look for Pneumothorax?

- No, No, No, definitely No!
- DISCONNECT the vent!
  - If rush of air, patient likely had auto PEEP due to breath stacking.

Vent troubleshooting

- If no rush of air…
  - Look for pneumo,
  - Suction ETT
  - Confirm tube placement
  - Change tube (ball valve mucous plug)

Super high peak flows?

Change the HME filter (heat and moisture exchanger)

A brief word on pharmacotherapy for obstruction

- Intubation does not fix the pathophysiology! Continue beta agonists, anti-muscarinics (Albuterol, Atrovent), your smooth muscle dilators (magnesium) etc. until they leave the ED.
- Rest those respiratory muscles with deep sedation!
- Propofol has bronchodilatory properties and is a good choice. So does Ketamine.
- Lots of opioids! Remember, they are hypercapneic, and therefore miserable.
  - Blunt their misery with high dose opioids!

Obstructive Strategy Review

- Assist Control
- 8ml/kg
- High IFR (80-100)
- Titrate FiO2 as needed
- PEEP = ZEEP
- RESPIRATORY RATE LOW start at 8-10.
  - I:E of 1:4 to 1:5

Lung Injury Pathway Summary:

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Questions?

References

- Emcrit.org “How to Dominate the Vent”
- ARDSNet
- Pubmed
- Uptodate