Positive Pressure Ventilation

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CFPC CoI Templates: Slide 1 – used in Faculty presentation only.

Faculty/Presenter Disclosure

- **Faculty:** Anish Mitra
- **Relationships with financial sponsors:**
  - **None**

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- **Potential for conflict(s) of interest:**
  - None

Mitigating Potential Bias

- Not necessary!

Outline

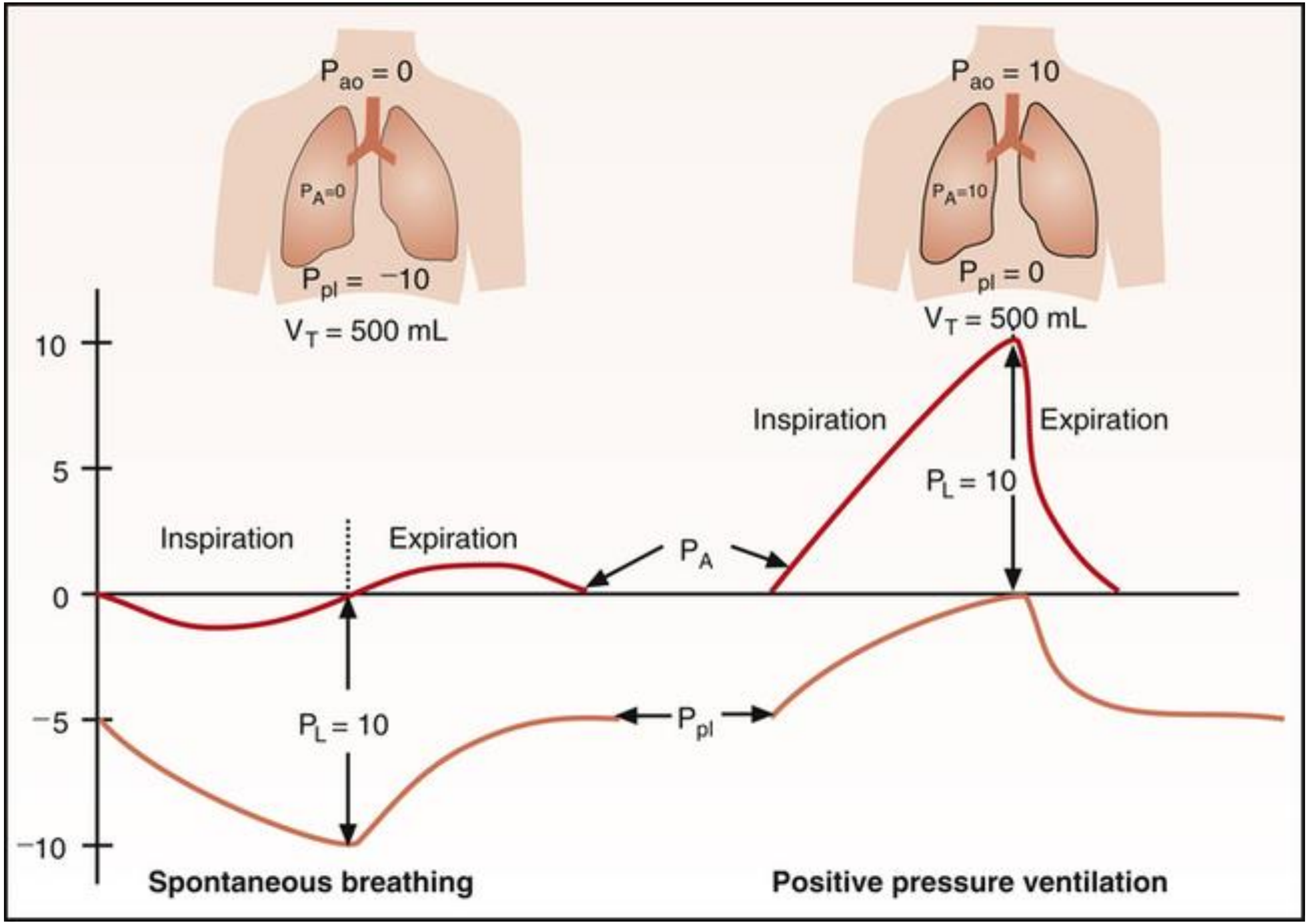
- Review physiology of positive pressure ventilation
- Non-invasive positive pressure ventilation
- Invasive mechanical ventilation
- Review evidence for mechanical ventilation
- Case

Physiology of Positive Pressure Ventilation

- Normal breathing is negative pressure ventilation
  - Diaphragm and intercostal muscles retract → creates negative pleural pressure/intrathoracic pressure → ↑ transpulmonary pressure gradient → air flows from atmosphere into lungs

Physiology of Positive Pressure Ventilation

- Positive pressure ventilation increases the external atmospheric pressure → increased pressure gradient causes air to flow into lungs → positive transpulmonary pressure → pleural pressure/intrathoracic pressure is positive



$P_{ao} = 0$
P_A=0
P_{pl} = −10
V_T = 500 mL
P_{ao} = 10
P_A=10
P_{pl} = 0
V_T = 500 mL
10
5
0
−5
−10
Inspiration
Expiration
P_A
Inspiration
Expiration
P_L = 10
P_L = 10
P_{pl}
Spontaneous breathing
Positive pressure ventilation

Physiology of Positive Pressure Ventilation

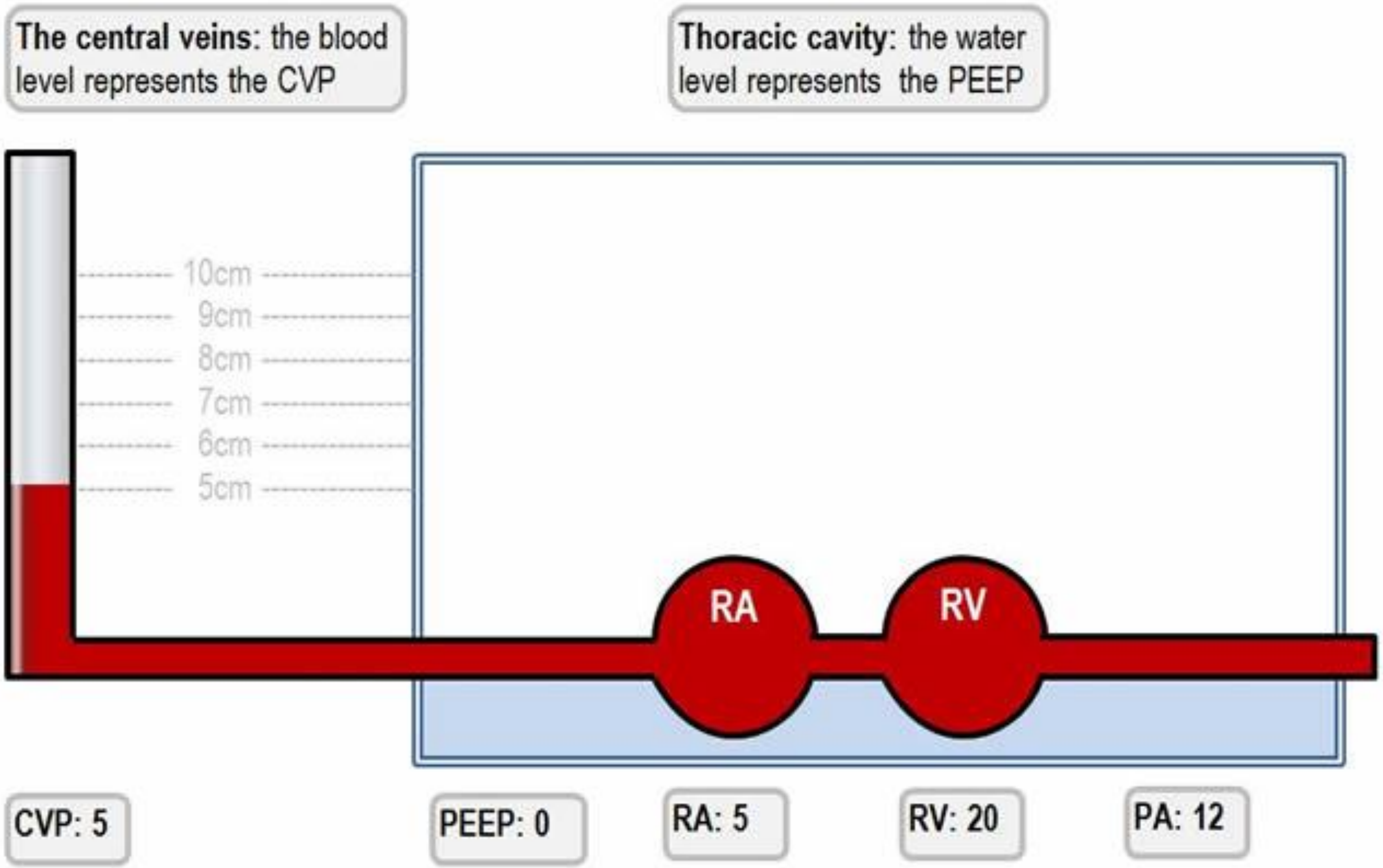
- Positive pressure ventilation increases the external atmospheric pressure → increased pressure gradient causes air to flow into lungs → positive transpulmonary pressure → pleural pressure/intrathoracic pressure is positive

- Positive transpulmonary pressure
  - Recruits collapsed alveoli
- Inspiratory (peak/plateau) – expiratory (PEEP) pressure gradient
  - Improves ventilation

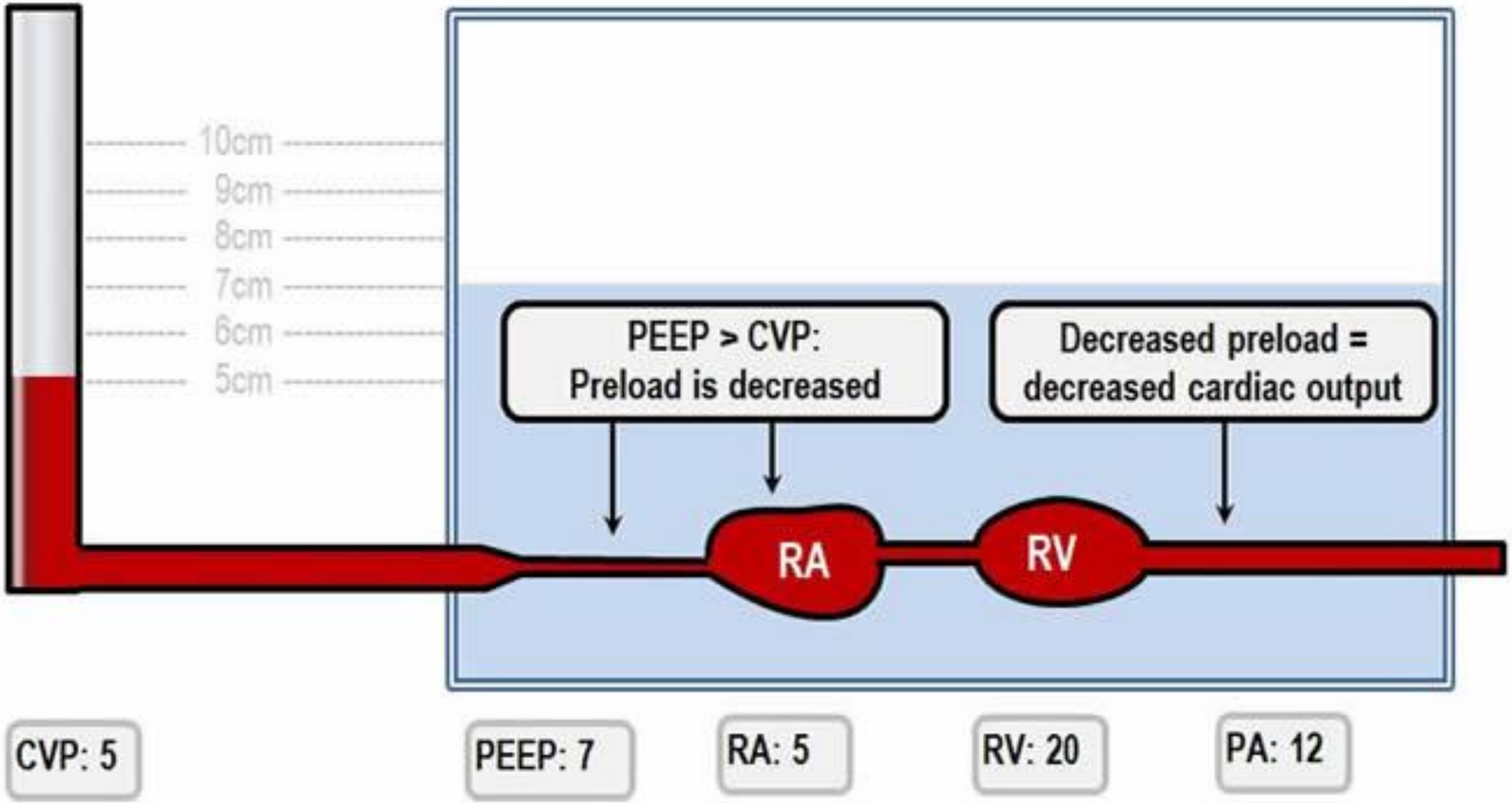
Cardiac Physiology of PPV

- Positive pressure ventilation increases the external atmospheric pressure → increased pressure gradient causes air to flow into lungs → positive transpulmonary pressure → pleural pressure/intrathoracic pressure is positive

- Positive intrathoracic pressure causes:
  - Decreases preload
  - Increases RV afterload
  - Decreased LV afterload



Deranged Physiology: https://derangedphysiology.com/main/cicm-primary-exam/required-reading/respiratory-system/Chapter%20523/effects-positive-pressure. 2018.



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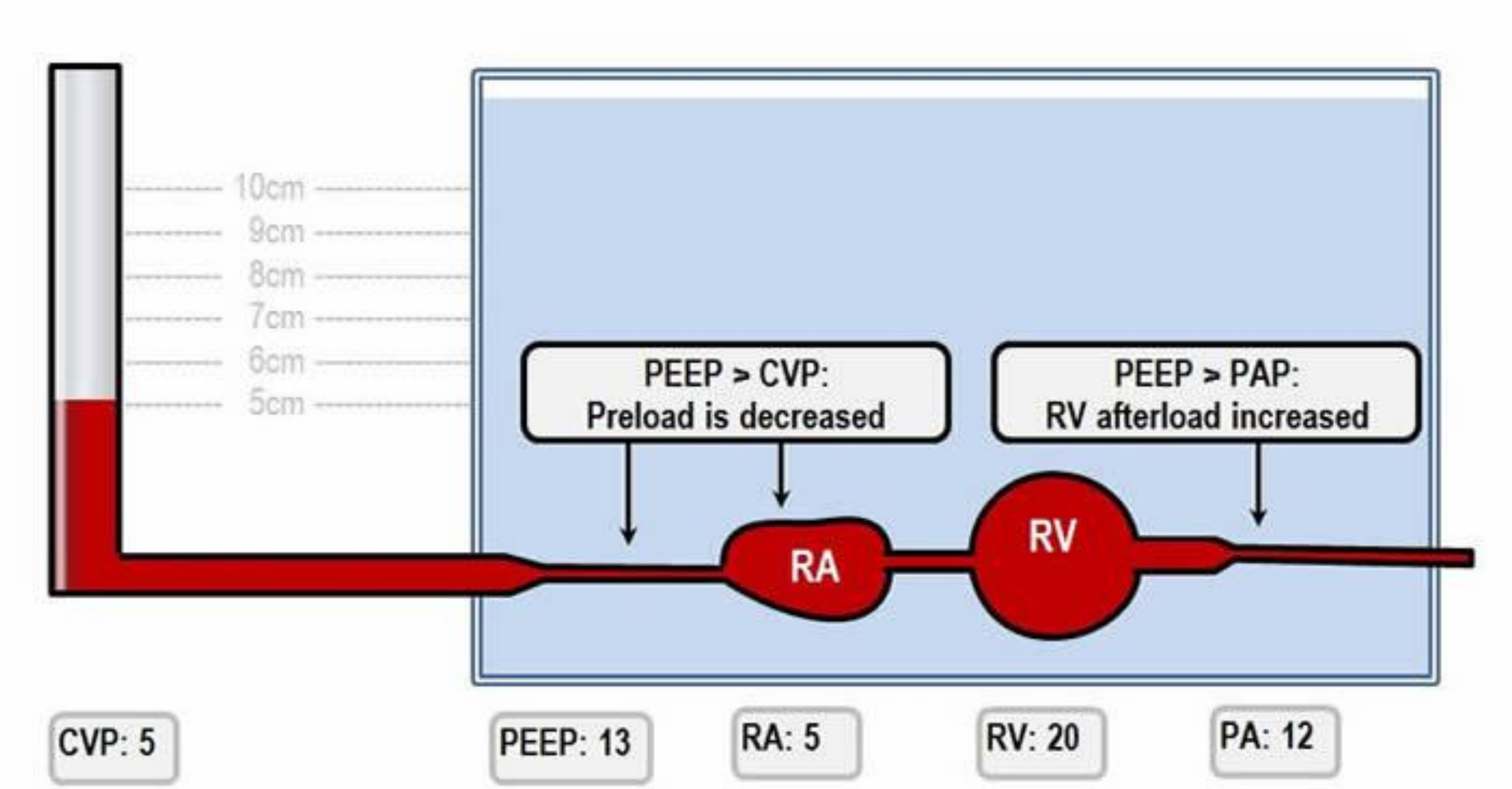

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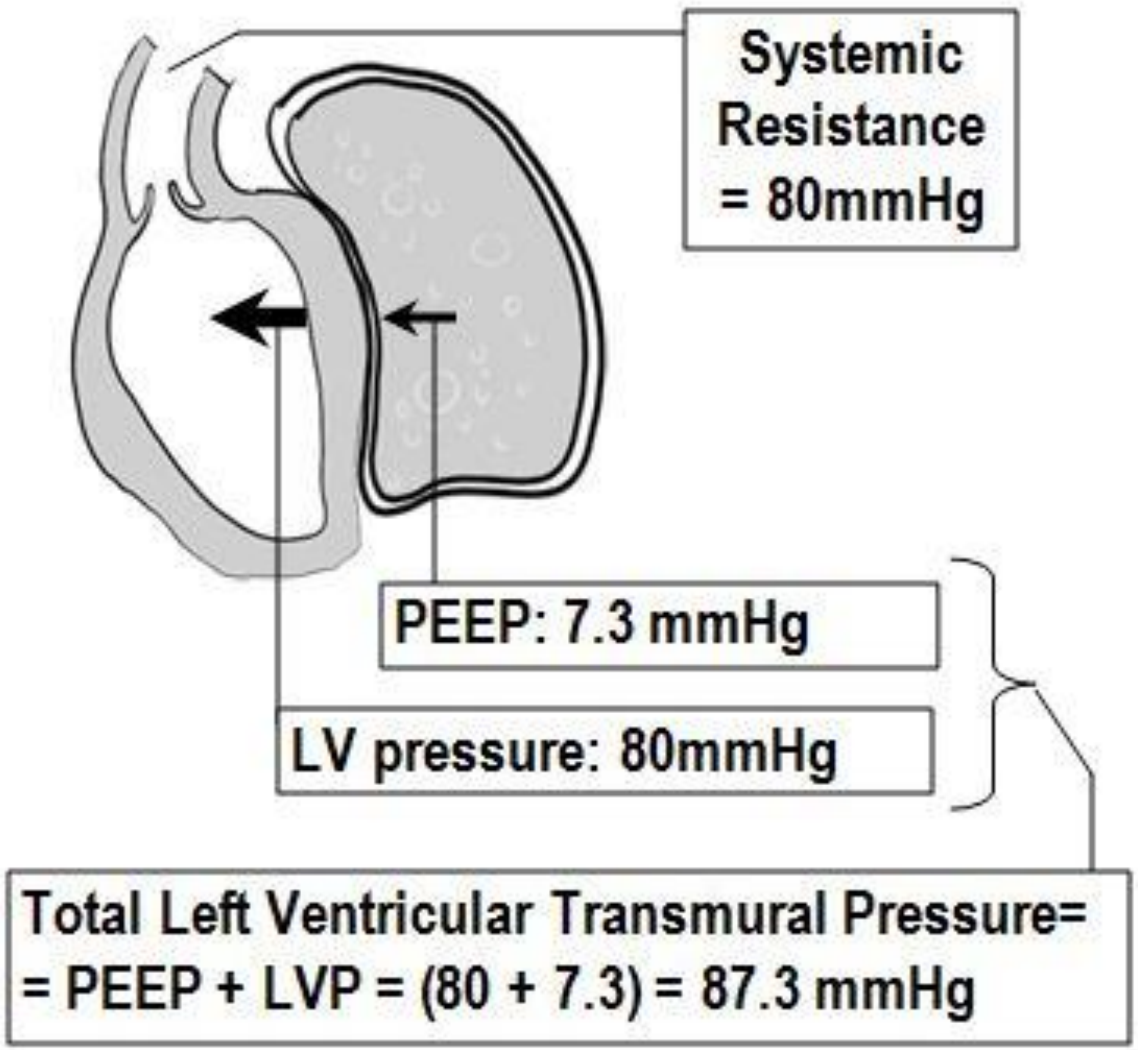

Deranged Physiology: https://derangedphysiology.com/main/cicm-primary-exam/required-reading/respiratory-system/Chapter%20523/effects-positive-pressure. 2018.

Physiology of Positive Pressure Ventilation

Pros

- Increases alveolar recruitment
- Improves ventilation
- Reduces LV afterload
- *Reduces preload*

Cons

- Increases RV afterload
- *Reduces preload*

Physiology of Positive Pressure Ventilation

- Why use positive pressure ventilation?
  - Improve ventilation
  - Improve oxygenation

Physiology of Positive Pressure Ventilation

- Ventilation
  - Proportional to respiratory rate and tidal volume
    - $V_{minute} = RR \; * Vtidal$
    - RR: possibly modifiable
      - Dependent on being able to set a respiratory rate in particular mode of ventilation
      - Patient must already be breathing less than the assigned respiratory rate
    - V_{tidal}: modifiable
      - ↑ V_{tidal}
      - Increase the pressure gradient
        - ↑ P_{IP} or ↓ PEEP

Physiology of Positive Pressure Ventilation

- Oxygenation
  - Proportional to FiO_2, mean airway pressure (MAP) and oxygenation index (OI)
    - $PaO_2 = \frac{FiO_2 * MAP}{OI}$
    - FiO_2: modifiable
    - $MAP = \frac{f * Ti}{60} * (P_{IP} - PEEP) + PEEP$: modifiable
    - Oxygenation index: partially modifiable
      - Calculated construct that is dependent on intrinsic function of respiratory system
      - Improving alveolar recruitment and hemodynamic stability will lower oxygenation index
  - Also reduces work of breathing
    - Normal WOB comprises 3% of body's oxygen consumption, but in respiratory failure can increase to 30%

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Non-Invasive Positive Pressure Ventilation

Definitions

- Non-invasive positive pressure ventilation (NIPPV)
  - Positive pressure ventilation without an endotracheal tube (CPAP/BiPAP)
- Continuous positive airway pressure (CPAP)
  - Positive end expiratory pressure (PEEP)
- Bilevel positive airway pressure (BiPAP)
  - Inspiratory positive airway pressure (IPAP)
  - Expiratory positive airway pressure (EPAP)
    - PEEP

Indications for NIPPV

- Acute respiratory failure
  - COPD exacerbation
    - pH < 7.35 and **relative** hypercarbia
      - *Clinical judgement > specific lab values*
    - ↑ ventilation through pressure gradient and ↑ alveolar recruitment and participation in gas exchange
  - Cardiogenic pulmonary edema
    - CPAP indicated before BiPAP
    - Contraindicated if patient is in cardiogenic shock or active ACS
  - Asthma exacerbation
    - Very controversial (should probably be avoided)
    - Patient must be closely monitored and ability to intubate must be onsite and available at all times
  - Hypoxia in immunosuppressed patients
    - Immunosuppressed for solid organ or bone marrow transplant or from chemotherapy

Sean P. Keenan, et al. Noninvasive Ventilation Guidelines Group. CMAJ February 22, 2011 183 (3) E195-E214; DOI: https://doi.org/10.1503/cmaj.100071

Indications for NIPPV

- Post extubation
  - Patients with COPD
  - High risk patients
    - Age > 65, hx of congestive heart failure, COPD, failure of previous weaning trials…
- Post operative
  - Post abdominal surgery
    - Controversial
    - Not commonly done
  - Respiratory post lung resection surgery
    - Controversial
    - Not commonly done

Sean P. Keenan, et al. Noninvasive Ventilation Guidelines Group. CMAJ February 22, 2011 183 (3) E195-E214; DOI: https://doi.org/10.1503/cmaj.100071

Indications for NIPPV

- Hypercapnic respiratory failure secondary to chest wall deformity (scoliosis, ankylosing spondylitis) or neuromuscular disease
- Obstructive sleep apnea
  - Chronic nocturnal use and acute hypercapnic decompensation

Non-invasive ventilation in acute respiratory failure Thorax 2002;57:192-211.

Contraindications for NIPPV

- Inability to protect airway
  - ↓ LOC
- Increased secretions
- Recent gastrointestinal surgery
- Craniofacial abnormalities
  - May not be possible to form mask seal
- Very unwell
  - …just intubate…
- Pneumothorax
  - Drain first

Approach to NIPPV

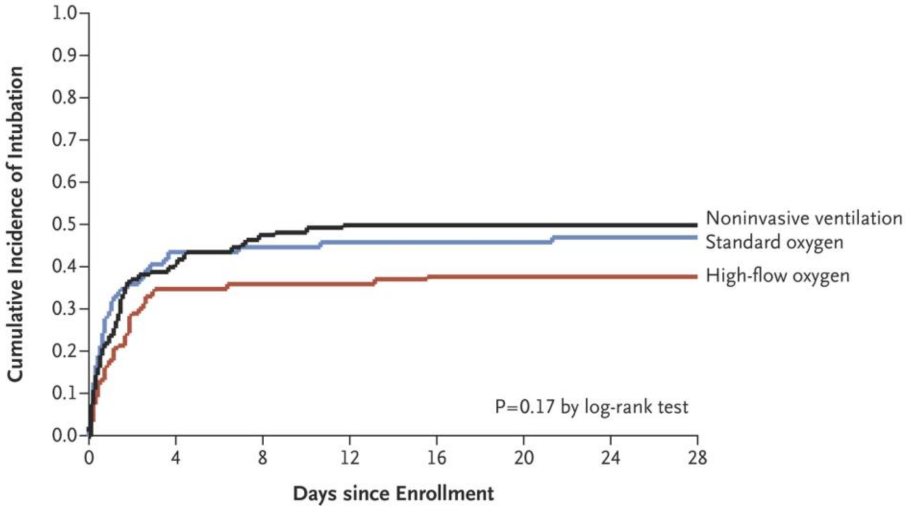
- Strongest evidence for COPD exacerbation and cardiogenic pulmonary edema
- Ensure no contraindications present
- Ensure good seal
  - Try different masks (if available)
- Set IPAP/EPAP
  - 10/5 or 12/8 are usually reasonable settings to start with
- Patient must be monitored closely
- Plan for duration of NIPPV and reassessment before starting…
  - ABG and trial removal of NIPPV after 2 hours…
- Intubate if patient is not clearly improving

High-Flow Oxygen

- Indications
  - Severe hypoxemic respiratory failure (PaO_2:FiO2 < 300)
    - No difference intubation compared to nasal canula or NIPPV
      - ? Sample size issue
    - ↑ ventilator free days
    - ↓ mortality

Frat JP, et al. High-flow oxygen through nasal cannula in acute hypoxemic respiratory failure. N Engl J Med. 2015 Jun 4;372(23):2185-96. doi: 10.1056/NEJMoa1503326.

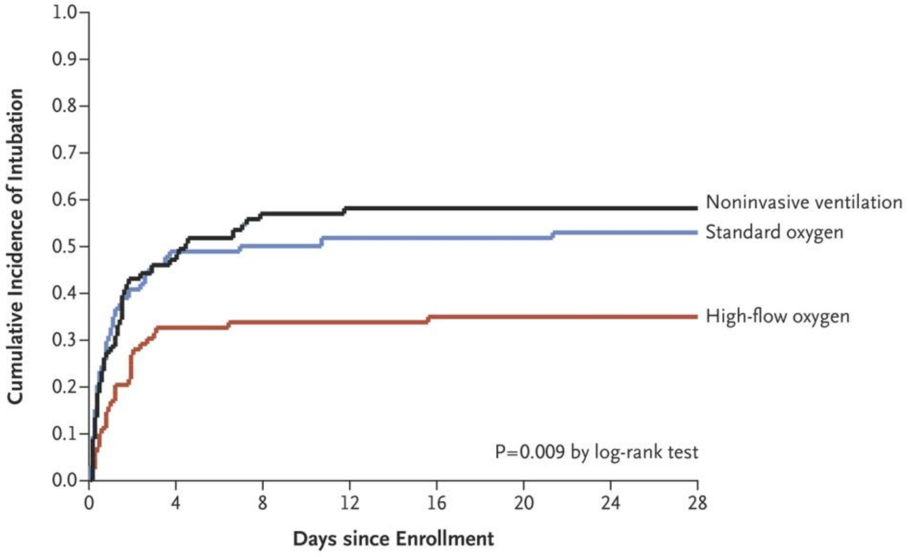
A Overall Population



No. at Risk

High-flow oxygen	106	68	67	67	65	65	65	65
Standard oxygen	94	52	50	49	49	49	48	48
Noninvasive ventilation	110	64	57	53	53	53	53	52

B Patients with a PaO_2:FIO_2 ≤200 mm Hg



No. at Risk

High-flow oxygen	83	55	54	54	53	53	53	53
Standard oxygen	74	37	35	34	34	34	33	33
Noninvasive ventilation	81	41	34	32	32	32	32	32

Invasive Mechanical Ventilation

Definition

- Invasive Mechanical Ventilation (IMV)
  - Positive pressure ventilation through an endotracheal tube (including trach)

Indications

- Refractory hypoxemia
- Refractory hypercapnia
- Increased work of breathing
- Airway protection
- Shock

Contraindications

- Not compatible with goals of care
- Airway cannot be captured

Modes of IMV

- Control mode ventilation
  - Assist control / volume control (AC/VC)
    - Modifiable variables: tidal volume, respiratory rate, FiO_2, PEEP, flow
    - Prototypical mode of ventilation
    - Least comfortable mode of ventilation
  - Pressure control (PC)
    - Modifiable variables: peak pressure, respiratory rate, FiO_2, PEEP
    - More comfortable mode than AC/VC
      - Patient not flow limited during spontaneous breaths

Modes of IMV

- Spontaneous mode ventilation
  - Pressure support ventilation (PSV)
    - Modifiable variables: peak pressure, FiO_2, PEEP
    - Most common mode of ventilation
    - Patient triggers ventilator
      - Pressure or flow triggered
    - Ventilator provides inspiratory pressure until expiratory pressure triggered
      - Usually 25% of peak flow
        - May need to modify if ventilator dysynchrony (e.g. severe COPD)

Approach to IMV

- Patient has indication and no contraindications for IMV
- Patient will likely need control mode ventilation after intubation due to sedation and paralysis preventing spontaneous breathing
- Plateau pressure should be < 30 cmH_2O and tidal volume should be 6-8 mL/kg (ideal body weight)
- Goal is to always transition to spontaneous mode ventilation as soon as possible unless patient needs to be deeply sedated
  - Typically due to severe respiratory failure or shock
- Wean ventilation as rapidly as possible
  - Daily spontaneous awakening trials and spontaneous breathing trials
- Extubate as soon as possible
  - Always ensure you have a reintubation plan in place!

Evidence Based Management

- ARDS
  - Low-tidal volumes[1]
    - Vt: 6-8 ml/kg and Pplateu < 30 cmH_2O
  - Deep sedation and paralysis[2]
    - Cisatracurium infusion
  - Proning[3]
  - ?ECMO[4]

1. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. N Engl J Med. 2000 May 4;342(18):1301-8.
2. Papazian L, et al. Neuromuscular blockers in early acute respiratory distress syndrome. N Engl J Med. 2010 Sep 16;363(12):1107-16. doi: 10.1056/NEJMoa1005372.
3. Guerin C, et al. Prone positioning in severe acute respiratory distress syndrome. N Engl J Med. 2013 Jun 6;368(23):2159-68. doi: 10.1056/NEJMoa1214103. Epub 2013 May 20.
4. Combes A, et al. Extracorporeal Membrane Oxygenation for Severe Acute Respiratory Distress Syndrome. N Engl J Med. 2018 May 24;378(21):1965-1975. doi: 10.1056/NEJMoa1800385.

Acute Respiratory Distress Syndrome

- Definition
  - Acute onset: within 7 days
  - Bilateral infiltrates on radiography
  - Non-cardiogenic pulmonary edema
  - PaO_2:FiO_2 (P:F) < 300

Evidence Based Management

- Spontaneous awakening trials
- Spontaneous breathing trials

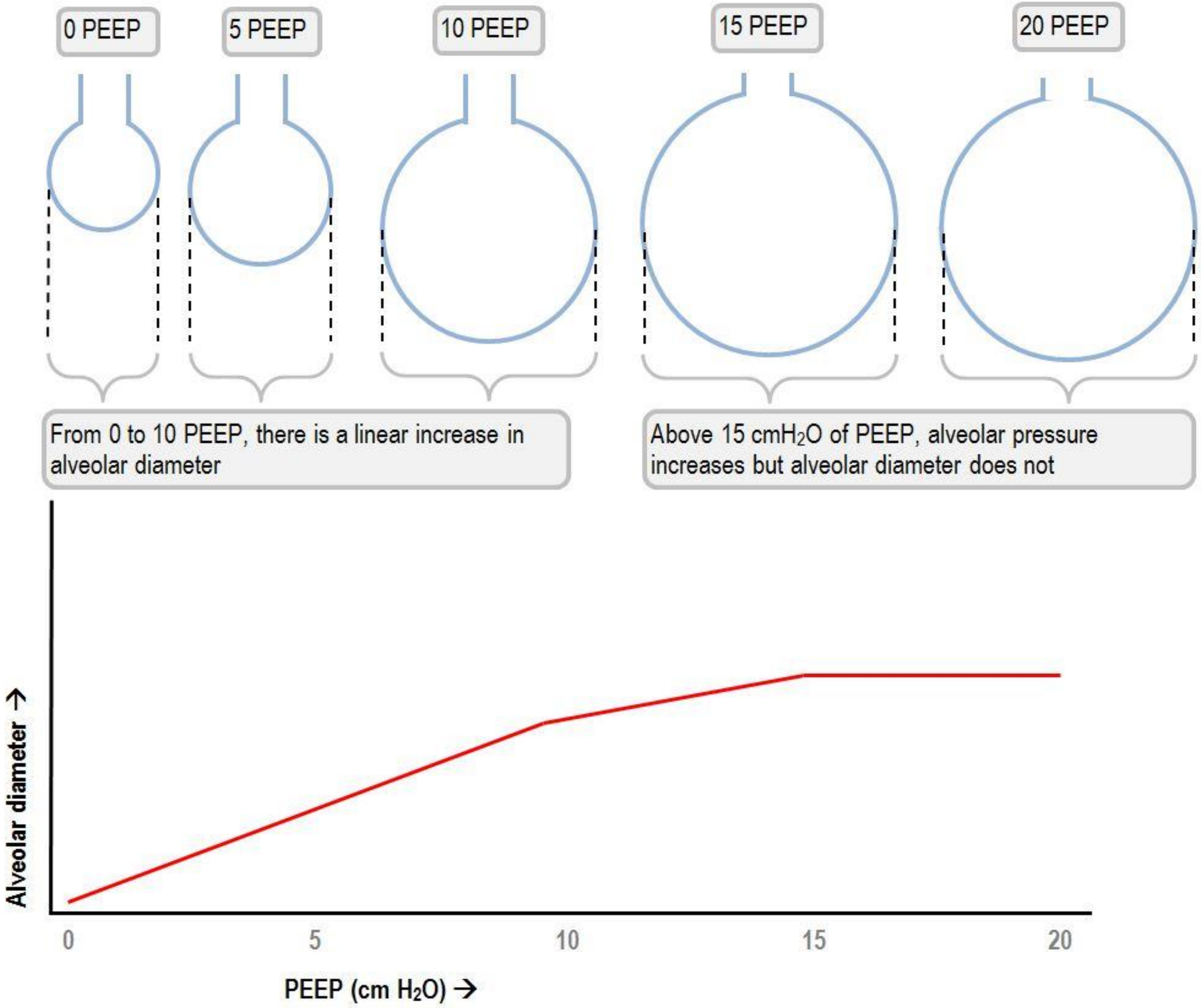
Ventilator Settings

- Can the patient tolerate spontaneous ventilation?
  - PSV if possible
- Target PaO_2: 80-100
  - Adjust PEEP and FiO_2 accordingly
- Target $PaCO_2$: 35-45
  - Set Vtidal/PC/PS and RR (if in controlled ventilation) accordingly

Choosing PEEP

- Stepwise increase in PEEP
  - Monitoring tidal volume, lung compliance, SpO_2, and hemodynamics
- PEEP table
  - Best evidence in ARDS*
- Esophageal balloon
  - EPVent2 study underway
- Stress index
- Pressure-Volume plots

Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. N Engl J Med. 2000 May 4;342(18):1301-8.


0 PEEP
5 PEEP
10 PEEP
15 PEEP
20 PEEP
From 0 to 10 PEEP, there is a linear increase in alveolar diameter
Above 15 cmH_2O of PEEP, alveolar pressure increases but alveolar diameter does not
Alveolar diameter →
0
5
10
15
20
PEEP (cm H_2O) →

Pulmonary Pitfalls of PEEP

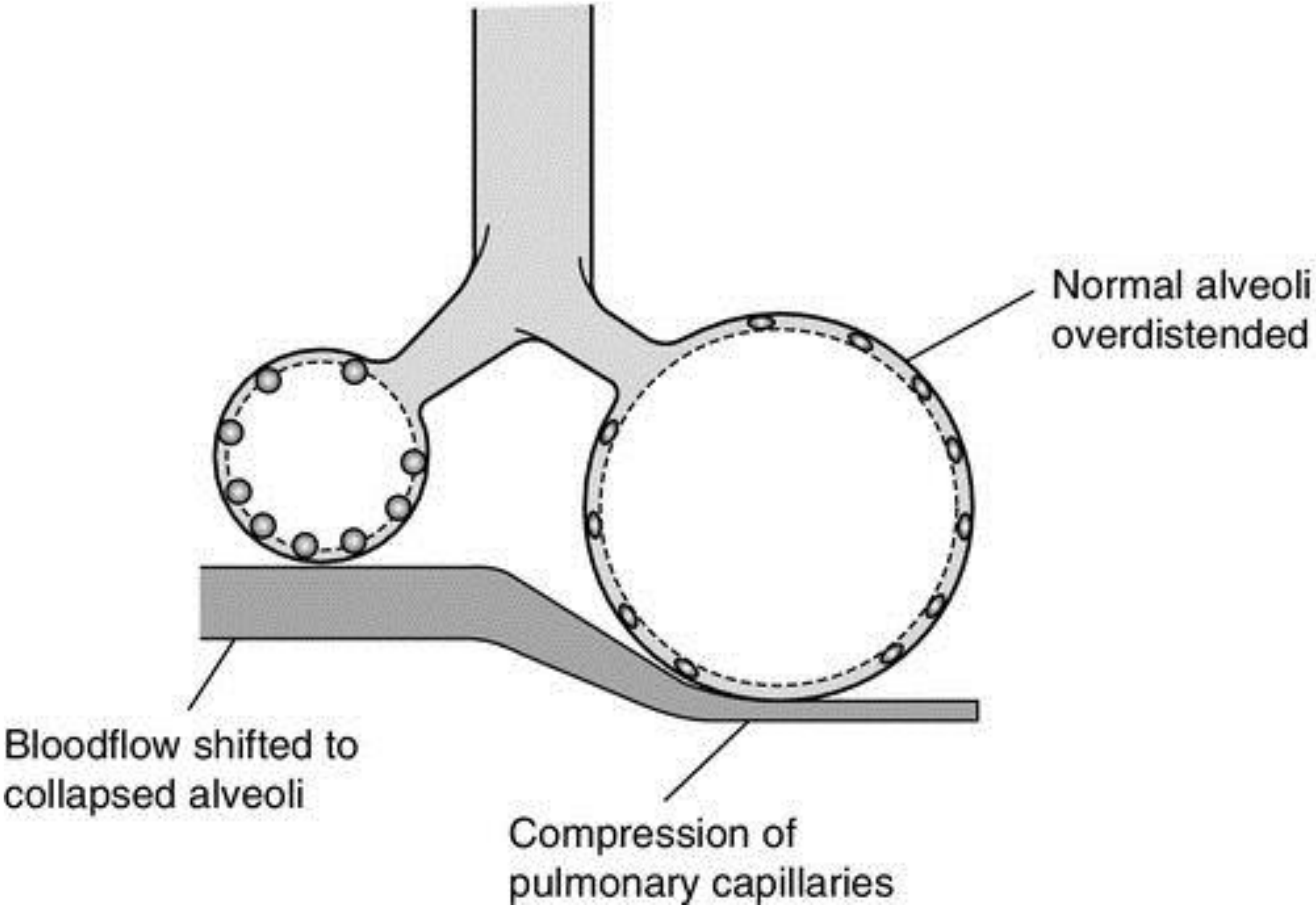


Table 1

Settings for Positive End-Expiratory Pressure (PEEP), According to the Required Fraction of Inspired (FiO_2).*

FiO_2	PEEP
0.3	5
0.4	5–8
0.5	8 10
0.6	10
0.7	10–14
0.8	14
0.9	14–18
1.0	18–24

*Settings are from the ARDSNet trial.[19] The required FiO_2 is the lowest value that maintains arterial oxyhemoglobin saturation above 90%.
corresponding level of PEEP is selected, arterial oxyhemoglobin saturation and plateau airway pressure should be monitored in the patient.

Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. N Engl J Med. 2000 May 4;342(18):1301-8.

Spontaneous Awakening Trial

- All sedatives and analgesics are stopped
  - Analgesia continued for pain

https://www.ahrq.gov/professionals/quality-patient-safety/hais/tools/mvp/modules/technical/sat-sbt-protocol.html

Spontaneous Awakening Trial

- Screening (avoid SAT if any of the following criteria are met)
  - Receiving a sedative infusion for active seizures or alcohol withdrawal.
  - Receiving escalating doses of sedative for agitation.
  - Receiving neuromuscular blockers.
  - Evidence of active myocardial ischemia in prior 24 hours.
  - Evidence of increased intracranial pressure.

https://www.ahrq.gov/professionals/quality-patient-safety/hais/tools/mvp/modules/technical/sat-sbt-protocol.html

Spontaneous Awakening Trial

- Stopping Criteria
  - Sustained anxiety, agitation, or pain.
  - Respiratory rate of 35 breaths/minute for at least 5 minutes.
  - Oxygen saturation (SpO_2) of less than 88% for at least 5 minutes.
  - Acute cardiac dysrhythmia.
  - Two or more signs of respiratory distress:
    - Tachycardia.
    - Bradycardia.
    - Use of accessory muscles.
    - Abdominal paradox.
    - Diaphoresis.
    - Marked dyspnea
- If patient fails SAT → restart sedation at half prior dosage and titrate up

https://www.ahrq.gov/professionals/quality-patient-safety/hais/tools/mvp/modules/technical/sat-sbt-protocol.html

Spontaneous Breathing Trial

- Minimal ventilatory support
  - T-tube circuit, CPAP 5 cmH2O, PSV 7/0, **PSV 5/5**
- Duration: 120 minutes (30 minutes)

https://www.ahrq.gov/professionals/quality-patient-safety/hais/tools/mvp/modules/technical/sat-sbt-protocol.html

Spontaneous Breathing Trial

- Screening (avoid SBT if any of the following criteria are met)
  - Inadequate oxygenation (SpO_2 < 88% or an F_iO_2 of ≥ 50% and a positive end-expiratory pressure [PEEP] ≥ 8 cm H_2O).
  - No spontaneous inspiratory effort in a 5-minute period (Consideration of the set respiratory rate is recommended).
  - Agitation.
  - Significant use of vasopressors or inotropes (patients may be on dopamine or dobutamine at ≤5 µg/kg/min or norepinephrine ≤2 µg/min, but may not be receiving any vasopressin or milrinone).[8]
  - Evidence of increased intracranial pressure.

https://www.ahrq.gov/professionals/quality-patient-safety/hais/tools/mvp/modules/technical/sat-sbt-protocol.html

Spontaneous Breathing Trial

- Stopping criteria
  - Respiratory rate of either fewer than 8 breaths per minute (bpm) or more than 35 bpm for 5 minutes or longer.
  - Hypoxemia ($SpO_2 < 88\%$ for ≥ 5 minutes).
  - Abrupt change in mental status.
  - Acute cardiac arrhythmia.
  - Two or more signs of respiratory distress:
    - Tachycardia.
    - Bradycardia.
    - Use of accessory muscles.
    - Abdominal paradox.
    - Diaphoresis.
    - Marked dyspnea.

https://www.ahrq.gov/professionals/quality-patient-safety/hais/tools/mvp/modules/technical/sat-sbt-protocol.html

Spontaneous Breathing Trial

- Passing criteria
  - SBT stopping criteria not met
  - Rapid Shallow Breathing Index (RSBI) or $F/V_t < 105$[1]

- Extubation criteria
  - Resolution of indication for IMV
  - Passed SBT (was delirium/agitation responsible for failure of extubation?)
  - Protecting airway (awake and ideally oriented)
  - Strong cough (importance dependent on amount of secretions)
  - Cuff leak

1. Yang KL, Tobin MJ. A prospective study of indexes predicting the outcome of trials of weaning from mechanical ventilation. N Engl J Med. 1991 May 23;324(21):1445-50.

Why bother with SATs and SBTs?

- ↓ days on mechanical ventilation
- ↓ days in ICU
- ↓ days in hospital
- ↓ mortality
  - NNT 7
- ↓ tracheostomy

- ↑ self extubation
  - Similar rates of reintubation after self extubation

1. Girard TD, et al. Efficacy and safety of a paired sedation and ventilator weaning protocol for mechanically ventilated patients in intensive care (Awakening and Breathing Controlled trial): a randomised controlled trial. Lancet. 2008 Jan 12;371(9607):126-34. doi: 10.1016/S0140-6736(08)60105-1.
2. Kress, JP, et al. Daily interruption of sedative infusions in critically ill patients undergoing mechanical ventilation. N Engl J Med. 2000 May 18;342(20):1471-7.
3. Minhas MA, et al. Effect of Protocolized Sedation on Clinical Outcomes in Mechanically Ventilated Intensive Care Unit Patients: A Systematic Review and Meta-analysis of Randomized Controlled Trials.. Mayo Clin Proc. 2015 May;90(5):613-23. doi: 10.1016/j.mayocp.2015.02.016. Epub 2015 Apr 9.

Approach to Weaning from Ventilator

- **Daily SATs and SBTs**
- Use short-acting sedation
  - Propofol/fentanyl

Sedation and Analgesia

- Short acting agents facilitate SATs and SBTs
  - Prolonged midazolam and fentanyl infusions can result in longer context sensitive half lives
- Some advocate for analgesia first sedation

Sedation and Analgesia

- Propofol related complications
  - Hemodynamic instability
  - Propofol infusion syndrome (rare!)
    - Definition
      - Acute refractory bradycardia progressing to asystole with one of the following:
        - Metabolic acidosis (lactic acidosis)
        - Rhabdomyolysis
        - Hyperlipidemia
        - Enlarged or fatty liver
    - Risk factors
      - > 67 mcg/kg/min for > 48 hours
      - Younger age
      - ↑ severity of illness
      - ↓ carbohydrate intake/high fat diet
    - Investigations
      - Ck
      - Triglycerides
      - Lactate
      - Cr

Approach to Weaning from Ventilator

- **Daily SATs and SBTs**
- Use short-acting sedation
  - Propofol/fentanyl
- Use least amount of sedation possible
  - RASS goal 0 unless there is a good reason to target deeper sedation
    - Severe respiratory failure, severe shock, severe traumatic brain injury
- Assess reason for SAT and SBT failure
  - The ETT can be very agitating and can induce delirium…extubation may help
- Rule of thumb: extubation failure rate should be ~ 5-10%
  - Not evidence based
  - Assumes physician comfort with reintubation

Tracheostomy

- Indications
  - Prolonged mechanical ventilation
    - No consensus on duration of time before transitioning to mechanical ventilation
    - ~ 7-14 days before most physicians would consider tracheostomy
- Contraindications
  - Not within scope of patients goals of care
  - Tracheostomy not possible

Tracheostomy

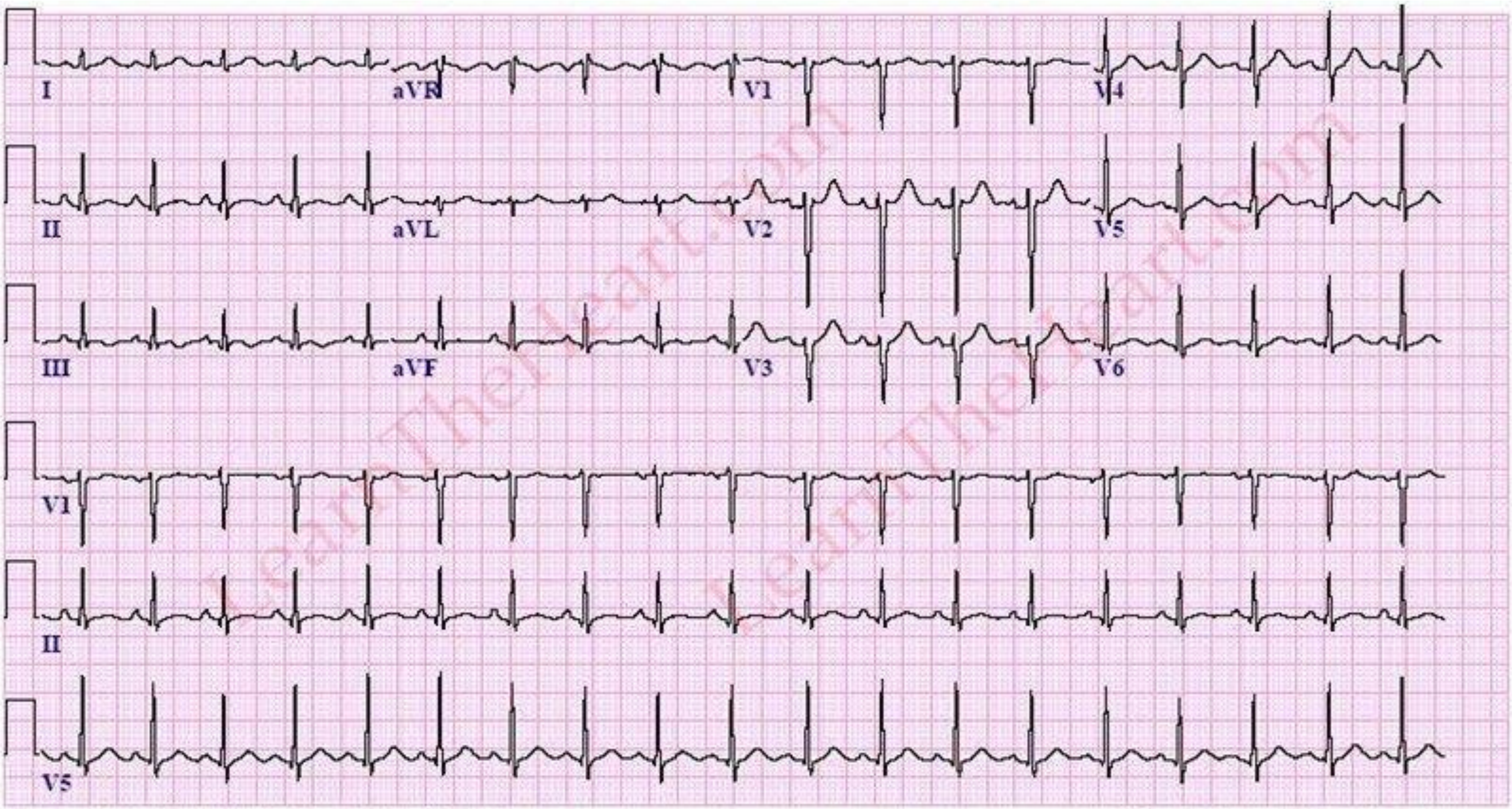
- Benefits
  - ↑ comfort
  - ↓ sedation
  - Early physiotherapy
  - Improved communication (↓ sedation and possibility of a speaking valve)
  - Improved oral hygiene
  - Possible oral feeding
  - More secure airway
  - ↓ weaning time
    - Evidence is contradictory
  - Facilitate transfer to ward

Case

- 64 yo F transferred from smaller community hospital for progressive respiratory failure.
- Presented to community hospital with 1-2 day history of increased work of breathing and dyspnea on exertion. Diagnosed with pneumonia and started on pip-tazo and azithromycin, but had progressive increase in oxygen requirements over 8 hours going from 2-15 LPM.
- Transferred to ER at local hospital and found to be alert and oriented, but ++dyspneic. BP 110/50, HR 115, RR 30, SpO2 89% on 15 lpm O2 via face mask

Case

- Hb 120, WBC 14.3, plts 310
- Na 140, K 4.0, Cl 104, HCO_3 18, lactate 6.2, trop 1.02
- pH 7.35, $PaCO_2$ 34, PaO_2 68



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Case

- Patient becomes acutely more agitated, significantly increased WOB, and SpO_2 85% on 15 lpm O_2

- Do you progress to optiflow, NIPPV, IMV or perform additional investigations?

Case

- Patient induced with an RSI and intubated successfully on first attempt. Initial end tidal CO_2 35 and SpO_2 92% on 100% FiO_2.
- 2 minutes later the $EtCO_2$ suddenly drops to 5 and the patient has a PEA cardiac arrest
- ROSC after one round of CPR…

Case

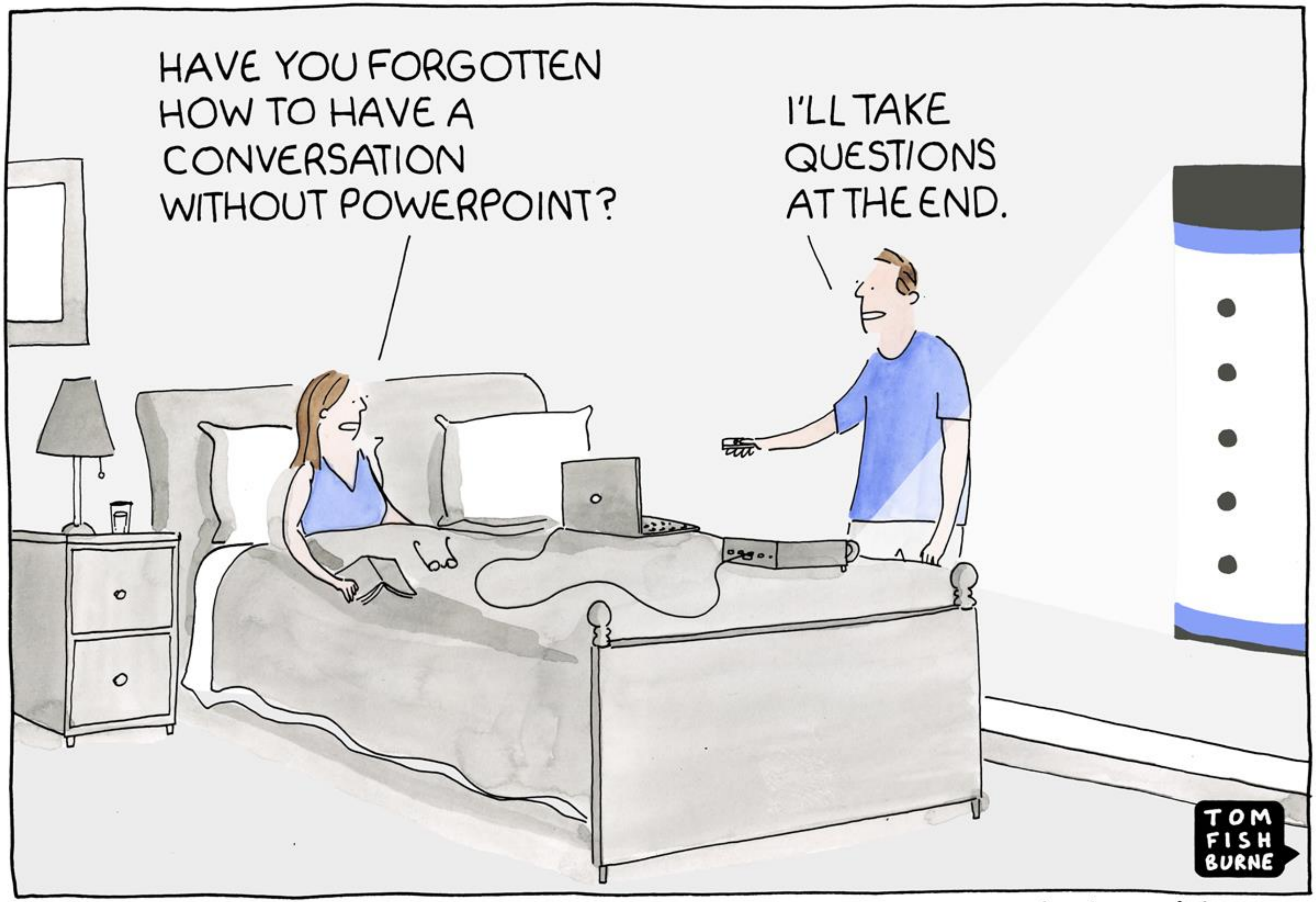
- Patient induced with an RSI and intubated successfully on first attempt. Initial end tidal CO_2 35 and SpO_2 92% on 100% FiO_2.
- 2 minutes later the $EtCO_2$ suddenly drops to 5 and the patient has a PEA cardiac arrest
- ROSC after one round of CPR…

Case

- Patient had saddle pulmonary embolism and a pulmonary embolism in transit through a PFO
- Positive pressure ventilation → ↑ RV afterload → ↓↓ cardiac output → cardiac arrest
- Surgical thrombectomy → VA ECMO
- Discharged from hospital 6 months later

Summary

- Review physiology of positive pressure ventilation
- Non-invasive positive pressure ventilation
- Invasive mechanical ventilation
- Review evidence for mechanical ventilation
- Case


HAVE YOU FORGOTTEN HOW TO HAVE A CONVERSATION WITHOUT POWERPOINT?
I'LL TAKE QUESTIONS AT THE END.
TOM FISH BURNE