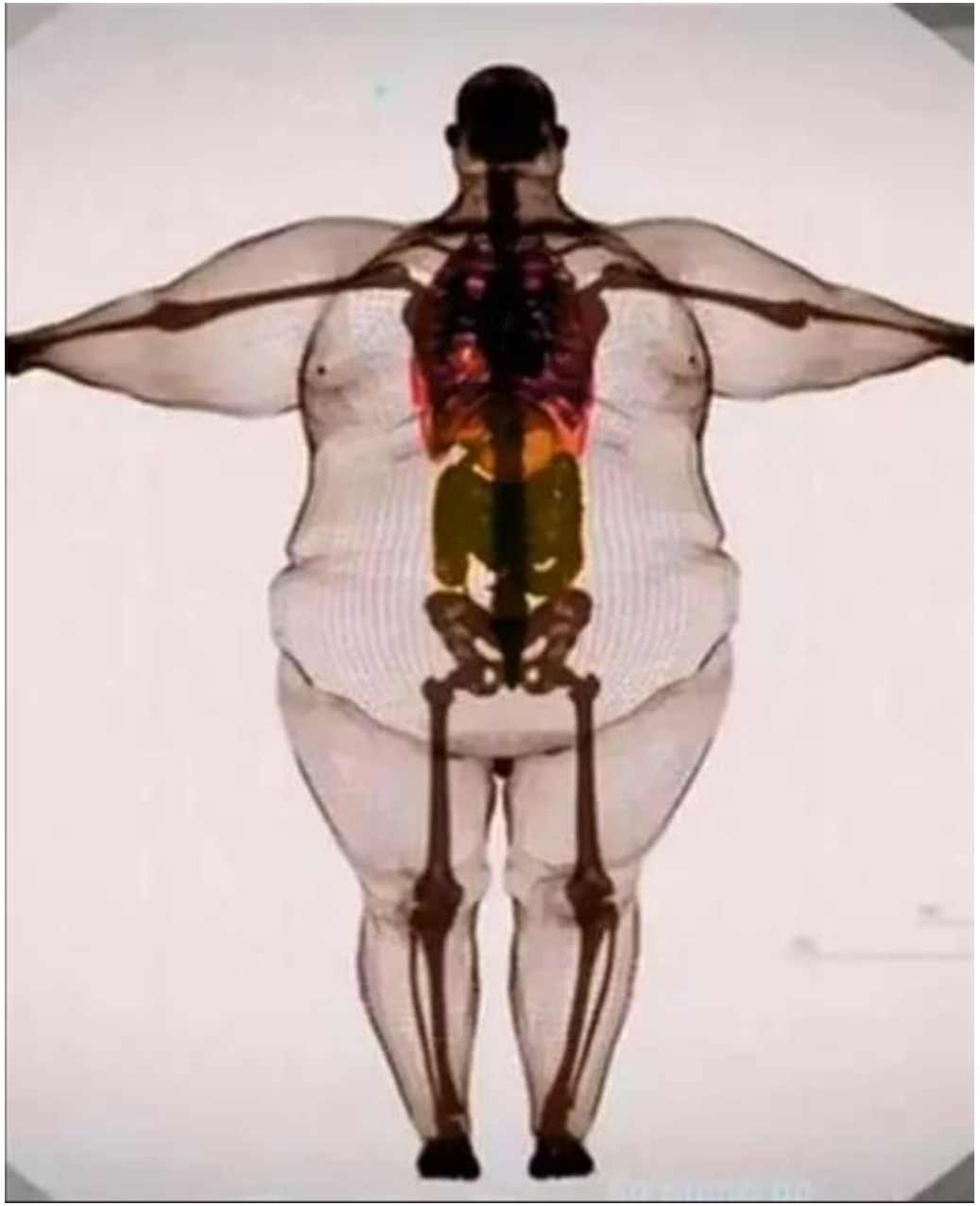
CHARLES VOLK, MD

PULMONARY AND CRITICAL CARE MEDICINE

High-Yield Topics in Ventilators

Overview

- PEEP titration strategies
- Recruit Maneuvers
- APRV
- Driving Pressure
- Pulmonary vasodilators
- Proning
- Paralysis
- ECMO



Tidal Volume

High PEEP vs Low PEEP strategy

- Debate as to which titration is best
  - Both appear similar in studies
  - *Per protocol* PEEP titration to a higher or a lower goal does not change outcomes
  - The higher PEEP table has been found to be generally more accepted in studies
- How about based on mechanics-based PEEP titration?

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

Brower RG, Lanken PN, MacIntyre N et al (2004) Higher versus lower positive end-expiratory pressures in patients with the acute respiratory distress syndrome. N Engl J Med 351:327–336. https://doi.org/10.1056/ NEJMoa032193 107. Meade MO, Cook DJ, Guyatt GH et al (2008) Ventilation strategy using low tidal volumes, recruitment maneuvers, and high positive endexpiratory pressure for acute lung injury and acute respiratory distress syndrome: a randomized controlled trial. JAMA 299:637–645. https:// doi.org/10.1001/jama.299.6.637 108. Mercat A, Richard J-CM, Vielle B et al (2008) Positive end-expiratory pressure setting in adults with acute lung injury and acute respiratory distress syndrome: a randomized controlled trial. JAMA 299:646–655. https://doi.org/10.1001/jama.299.6.646

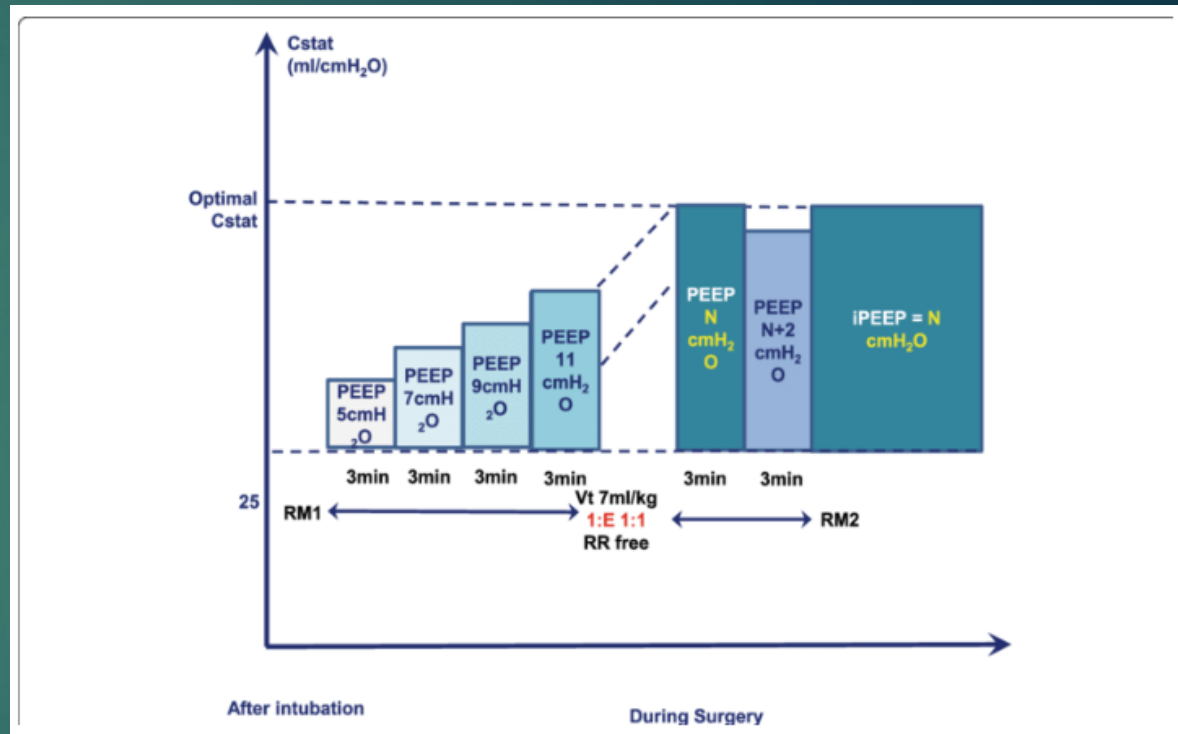
Mechanics-Based PEEP Titration

- Recent trials using titration of PEEP based on:
  - Esophageal pressure (transpulmonary pressure)
  - Static Compliance-Based
  - Lung Recruitment-Based PEEP titration
- Using esophageal pressure and static compliance showed no benefit and no harm
  - Using static compliance improved hemodynamic instability, but no overall change in outcomes
- The 2017 ART trial found ***increased*** mortality in using recruitment maneuvers to titrate PEEP

Talmor D, Sarge T, Malhotra A et al (2008) Mechanical ventilation guided by esophageal pressure in acute lung injury. N Engl J Med 359:2095– 2104. https://doi.org/10.1056/NEJMoa0708638 110. Beitler JR, Sarge T, Banner-Goodspeed VM et al (2019) 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: a randomized clinical trial. JAMA 321:846–857. https://doi.org/10.1001/jama.2019.0555 111. Pintado M-C, de Pablo R, Trascasa M et al (2013) Individualized PEEP set- ting in subjects with ARDS: a randomized controlled pilot study. Respir Care 58:1416–1423. https://doi.org/10.4187/respcare.02068 112. Writing Group for the Alveolar Recruitment for Acute Respiratory Distress Syndrome Trial (ART) Investigators, Cavalcanti AB, Suzumura EA et al (2017) Effect of lung recruitment and titrated positive endexpiratory pressure (PEEP) vs low PEEP on mortality in patients withacute respiratory distress syndrome: a randomized clinical trial. JAMA 318:1335–1345. https://doi.org/10.1001/jama.2017.14171

Static Compliance (Cstat) PEEP Titration

- Cstat = tidal volume / (plateau pressure − total PEEP)
- Start at a high PEEP (~20cm H_2O) and decrease stepwise by 2-3cm H_2O, measuring at each step
- Choose the PEEP with the highest Cstat that keeps plateau pressure ≤ 30 cm H_2O and driving pressure ≤ 15 cm H_2O

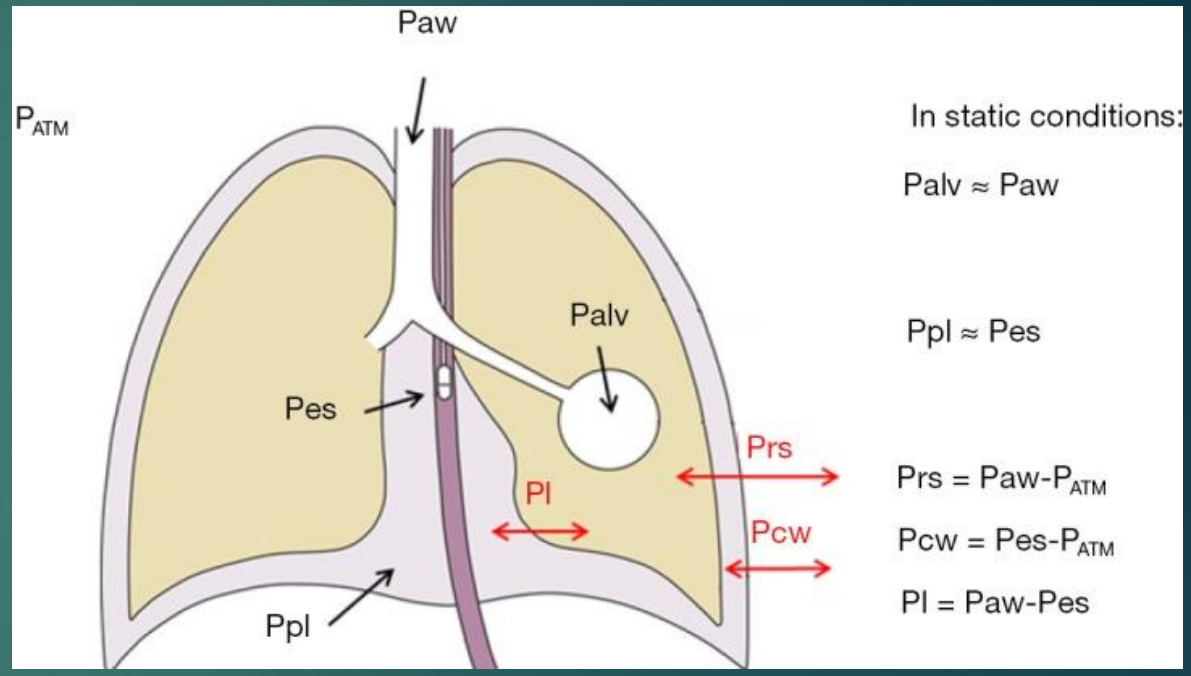


Individualized PEEP titrated by optimal Cstat. Cstat static lung compliance, PEEP positive end-expiratory pressure, iPEEP individualized positive end-expiratory pressure, RM the ventilator-driven alveolar recruitment maneuver

Wang QY, Ji YW, An LX, Cao L, Xue FS. Effects of individualized PEEP obtained by two different titration methods on postoperative atelectasis in obese patients: study protocol for a randomized controlled trial. Trials. 2021 Oct 15;22(1):704. doi: 10.1186/s13063-021-05671-1. PMID: 34654446; PMCID: PMC8517565.

Transpulmonary Pressure

- Esophageal Pressure Monitor
- Used to estimate the pleural pressure
  - PL = Paw – Pes
- Goal is to achieve a slightly positive end-expiratory transpulmonary pressure (PL)
  - About 0-2cm H_2O
- Especially useful in obesity or high intraabdominal pressure
- Calibration and experience are necessary



Umbrello M, Chiumello D. Interpretation of the transpulmonary pressure in the critically ill patient. Ann Transl Med. 2018 Oct;6(19):383. doi: 10.21037/atm.2018.05.31. PMID: 30460257; PMCID: PMC6212359.

EPVEnt-2 Trial (2019)

In patients assigned to empirical high PEEP, titration was performed according to the following table:

Empirical High PEEP Titration Table																	
Step	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
FiO_2	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.9	1.0	1.0
PEEP	5	8	10	10	12	14	16	18	18	20	20	20	20	22	22	22	24

In both groups, tidal volume of 6 mL/kg predicted body weight (PBW) was targeted. If plateau transpulmonary pressure exceeded 20 cm H_2O (P_{ES}-guided PEEP group) or plateau airway pressure exceeded 35 cm H_2O (empirical high-PEEP group), tidal volume was decreased to 5 or 4 mL/kg PBW as necessary. Respiratory rate, pH, partial pressure of arterial CO_2 ($PaCO_2$) and oxygen (PaO_2) were targeted according to protocol, with ranges adopted from the NIH ARDS Network trials.[7]

PLATEAU PRESSURE GOAL: ≤ 30 cm H_2O

Check Pplat (0.5s insp. pause) q4h and after any PEEP/V_t change:

- If Pplat > 30: ↓ V_t in 1 ml/kg steps (min = 4 ml/kg)
- If Pplat < 25 and V_t < 6: ↑ V_t in 1 ml/kg steps until Pplat ≥ 25 or V_t = 6
- If Pplat < 30 and breath stacking or dyssynchrony: ↑ V_t to 7–8 ml/kg if Pplat stays ≤ 30

pH GOAL: 7.30–7.45

Acidosis Management (pH < 7.30):

If pH 7.15–7.30: Increase RR until pH > 7.30 or $PaCO_2$ < 25 (Maximum set RR = 35).

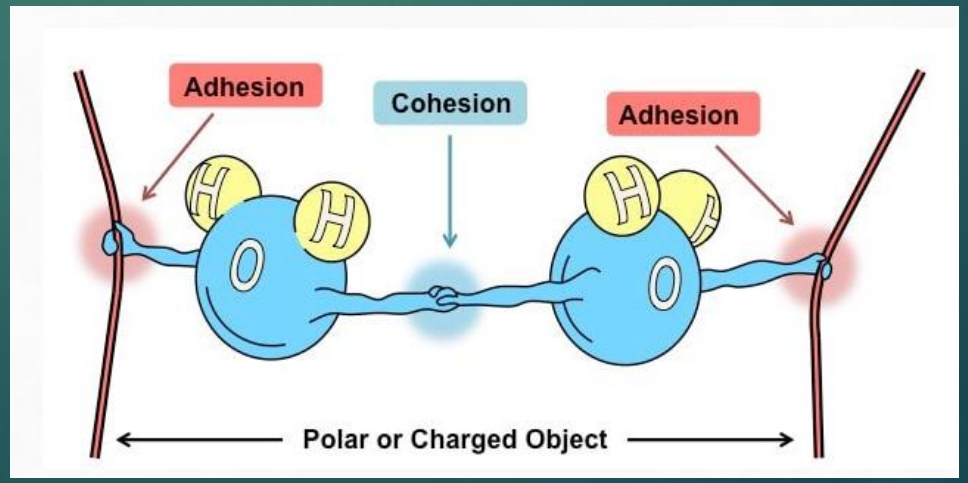
If pH < 7.15: Increase RR to 35. If pH remains < 7.15, V_T may be increased in 1 ml/kg steps until pH > 7.15 (Pplat target of 30 may be exceeded).

May give $NaHCO_3$.

Alkalosis Management (pH > 7.45): Decrease vent rate if possible.

Recruitment Maneuvers

- A broad definition of a temporary increase in airway pressures to "recruit" areas of atelectatic lung
  - The idea is that it "pops" them open and then the PEEP can maintain them in an open state
  - Idea is to break water cohesion to allow alveoli to remain open
- Risky overall due to overdistention, barotrauma, and hemodynamic changes/collapse



Biology4me Dr. Suris Class. SC.912.L.18.12 Properties of Water - Welcome to Dr. Suris Science Class!

Recruitment Trials

- Hodgson et al. in 2011 and in 2019 (PHARLAP trial) evaluated a prolonged "staircase" recruitment maneuvers in which PEEP was set to 20, 30, and then 40 cmH2O for 2 min each, followed by a decremental PEEP titration to 15 cmH2O or until desaturation
- Kung et al. evaluated a recruitment maneuver in which PEEP was set to 35 cmH2O for two minutes followed by decremental PEEP titration until maximum compliance was identified
- Chung et al. evaluated an RM consisting of raising PEEP from 10 to 40 cmH2O in increments of 5 cmH2O, with 40 seconds at each recruitment, followed by a decremental PEEP titration
- All were small and had methodological issues

ART Trial (2017)

- Considered the highest quality of the recruitment trials and had to change its protocol due to three cardiac arrests during recruitment maneuvers
- Method: PEEP to 35-40cm H_2O for 2 minutes, then decreased in 2cm H_2O increments every 2 minutes
- Given this trial's validity, the authors of the European Society of Intensive Care Medicine guidelines accepted this as the best done of the available studies
- Routine recruitment maneuvers are **recommended against** due to the increase in mortality and no evidence of any benefit

How about brief recruitment?

- Generally ~40 seconds at high pressure
  - Kacmarek et al 2016
  - Meade et al 2008
  - Xi et al 2010
- None found any real benefit and potential harms

Recruitment Maneuvers

- Generally found either to be ineffective or actively harmful
- No longer recommended for any patients

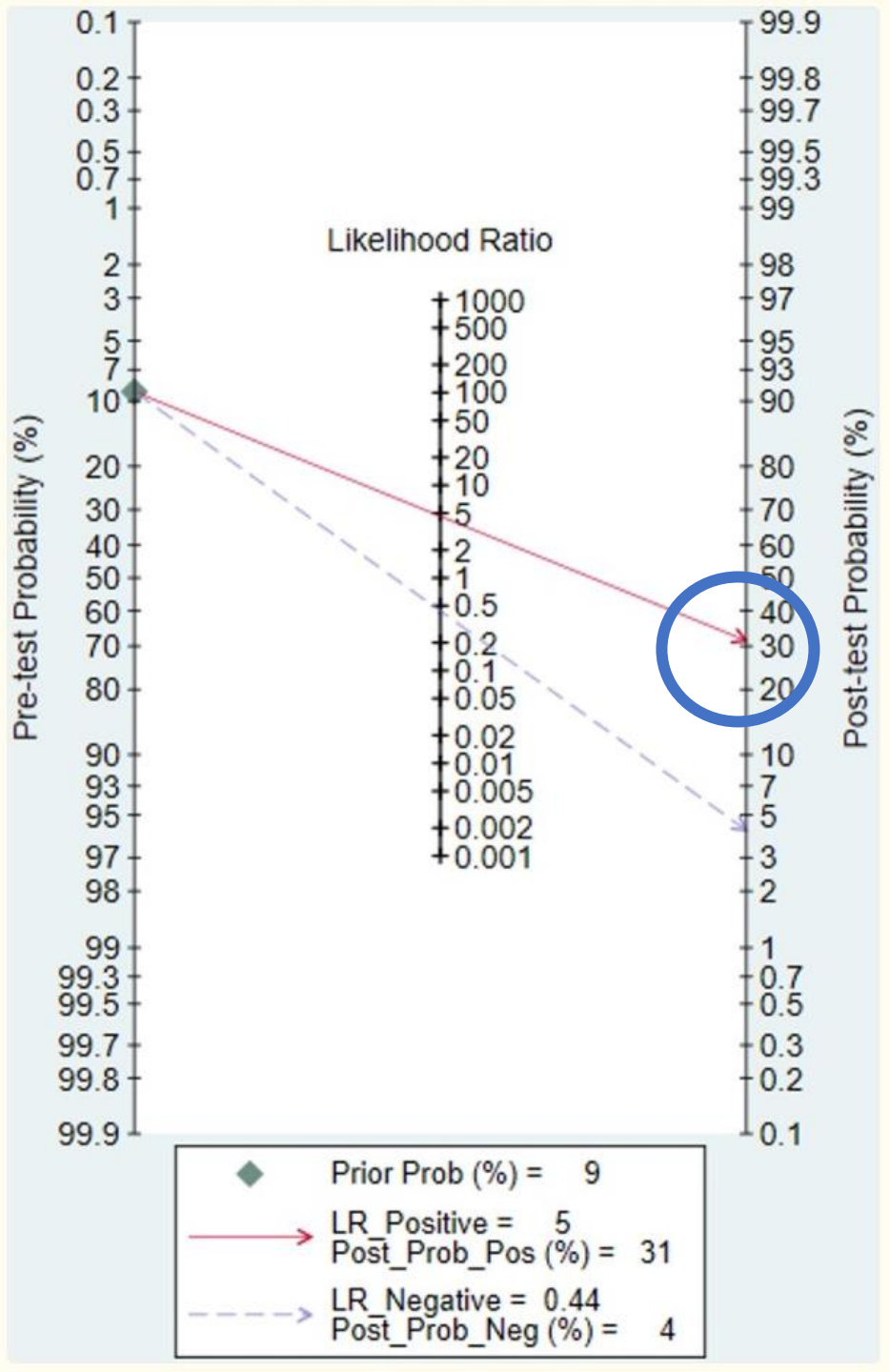
Air Leak Testing

- Leak of air around the ETT cuff when fully deflated
- We will often use a qualitive "how much noise do I hear" vs using a quantitative inspiratory tidal volume(VTi) minus expiratory tidal volume (VTe)
  - VTi – VTe = Leak
  - Normal leak volume: >110–130 mL or >10–15% of VTi

Kuriyama A, Jackson JL, Kamei J. Performance of the cuff leak test in adults in predicting post-extubation airway complications: a systematic review and meta-analysis. Crit Care. 2020 Nov 7;24(1):640. doi: 10.1186/s13054-020-03358-8. PMID: 33160405; PMCID: PMC7648377.

Air Leak Testing

- Qualitative (noise-based) testing has abysmal sensitivity
  - 35% - meaning it only catches a third of people with post extubation stridor
- Quantitative has better sensitivity
  - But still only 62% - a third of patients still go unrecognized
- Both qualitative and quantitative have good specificity
  - Upwards of 90%
- However, the actual likelihood of postexpiratory obstruction is still relatively low
  - No cuff leak, about 30% likelihood
  - Low incidence and thus low predictive value



Air Leak Testing

- **Who to consider testing:**
  - Prolonged intubation (>48–72 hrs)
    - Some say 6 days
  - Traumatic or multiple intubation attempts
  - Large ETT relative to patient size
  - History of airway edema, inhalation injury, or anaphylaxis
- Not recommended for routine testing
  - Low positive predictive value means that most positive tests (no leak) have no issues

APRV

- Also known as "Bi-Level" or "Bi-Vent"
- A strategy to improve oxygenation by using inverse breathing
  - Majority of time in inhalation
  - Uses autopeep intentionally
- Zhou 2017 showed improved outcomes, but significant methodological issues
  - APRV is a salvage mode and no change in outcomes

Figure 9.9.1: PC-APRV with spontaneous breathing on Phigh level by Drägerwerk AG & Co. KGaA. Used under fair dealing. All Rights Reserved.

APRV

- The end state of inverse ratio ventilation
  - More time spent in inhalation than in exhalation
  - Allows greater mean airway pressure of oxygen and better blood oxygenation
  - Utilizes physics to improve oxygenation at the cost of worsened ventilation and CO2 removal
- Very uncomfortable and needs deep sedation
- Useful in select cases

Driving Pressure (ΔP)

- Plateau pressure minus PEEP
  - ΔP = Pplat – PEEP
- The pressure/power required to inflate the lungs
- Must measure accurate plateau pressures
  - This may require paralysis to perform accurately
- Driving pressures >15 are associated with increased mortality
  - Is this just a marker of severity?
  - No randomized control trials have found that targeting ΔP <15 improves outcomes
  - Risks of hypoventilation and acidosis

Inhaled Epoprostenol (Flolan/Veletri)

- Supplanted the prior use of inhaled nitric oxide (iNO)
  - Less cumbersome, fewer specialized equipment pieces
  - Cheaper and safer
- Causes vasodilation in ventilated alveoli, improving VQ mismatching
- Has never been found to improve outcomes or mortality
- Rescue for refractory hypoxemia

Inhaled Epoprostenol (Flolan/Veletri)

- Outside of ARDS, may have benefits in pulmonary hypertension
- In patients with pulmonary hypertension, perioperative use of inhaled epoprostenol have been found to improve outcomes in very select patients
  - Difficult to generalize
  - Pulmonary hypertension is a heterogenous family of diseases and unified treatment plans are impossible
- Can cause cardiovascular collapse though thankfully are short-lived

McGlothlin DP, Granton J, Klepetko W, Beghetti M, Rosenzweig EB, Corris PA, Horn E, Kanwar MK, McRae K, Roman A, Tedford R, Badagliacca R, Bartolome S, Benza R, Caccamo M,Cogswell R, Dewachter C, Donahoe L, Fadel E, Farber HW, Feinstein J, Franco V, Frantz R, Gatzoulis M, Hwa Anne Goh C, Guazzi M, Hansmann G, Hastings S, Heerdt PM, Hemnes A,Herpain A, Hsu CH, Kerr K, Kolaitis NA, Kukreja J, Madani M, McCluskey S, McCulloch M, Moser B, Navaratnam M, Rådegran G, Reimer C, Savale L, Shlobin OA, Svetlichnaya J, SwetzK, Tashjian J, Thenappan T, Vizza CD, West S, Zuckerman W, Zuckermann A, De Marco T. ISHLT consensus statement: Perioperative management of patients with pulmonaryhypertension and right heart failure undergoing surgery. J Heart Lung Transplant. 2022 Sep;41(9):1135-1194. doi: 10.1016/j.healun.2022.06.013. Epub 2022 Jun 23. PMID: 36123001

Prone Positioning

- PROSEVA trial (2013)
  - Drastic mortality improvement (17.6% absolute mortality improvement), now considered standard of care in ARDS
- Start as soon as feasible after stabilization
- Continue as long as the PaO2/FiO2 ratio (the "P to F ratio") is <150
- Apply for 16 hours or more per day
  - No one knows the best duration
- Rotaprone bed is not superior
  - Definitely more expensive

Corollary – Awake Proning

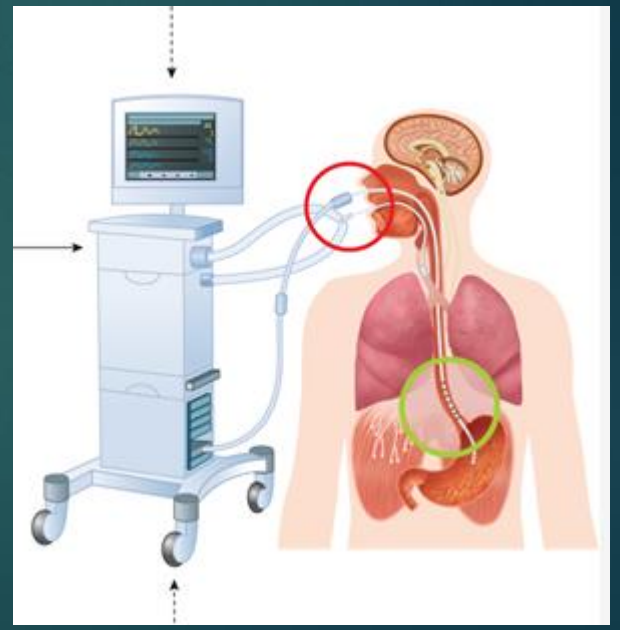
- During COVID-19, we would have an awake patient spend time proning on high flow or NIPPV
- Found to have a slight decrease in the risk of intubation specifically in COVID-19
- No change in mortality and no data for other ARDS causes
- Relatively easy to do and the mechanism makes sense
- A weak recommendation to try

Paralysis

- Early, smaller studies found significant benefit but the much larger ACURASYS (2019) found definite harm and increased mortality
  - This is for routine use
  - We reserve the use of neuromuscular blockade for ventilator dyssynchrony that does not respond to improved sedation
  - In my experience, it is needed in about half of ARDS cases

NAVA – Neurally Adjusted Ventilatory Assist Ventilation

- A type of proportional-assist ventilation
  - Instead of us choosing the inspiratory support, the ventilator varies the IPAP based on physiologic values
- An esophageal probe is inserted to the level of the diaphragm
- Diaphragm muscle activation is measured in volts
  - The ventilator gives support based on the effort of the patient
- Can be an elegant way to wean patients from ventilators
- More common in NICU/PICU environments
- Specific to the Maquet brand



Neurally Adjusted Ventilatory Assist | Anesthesia Key

Extracorporeal Membrane Oxygenation (ECMO)

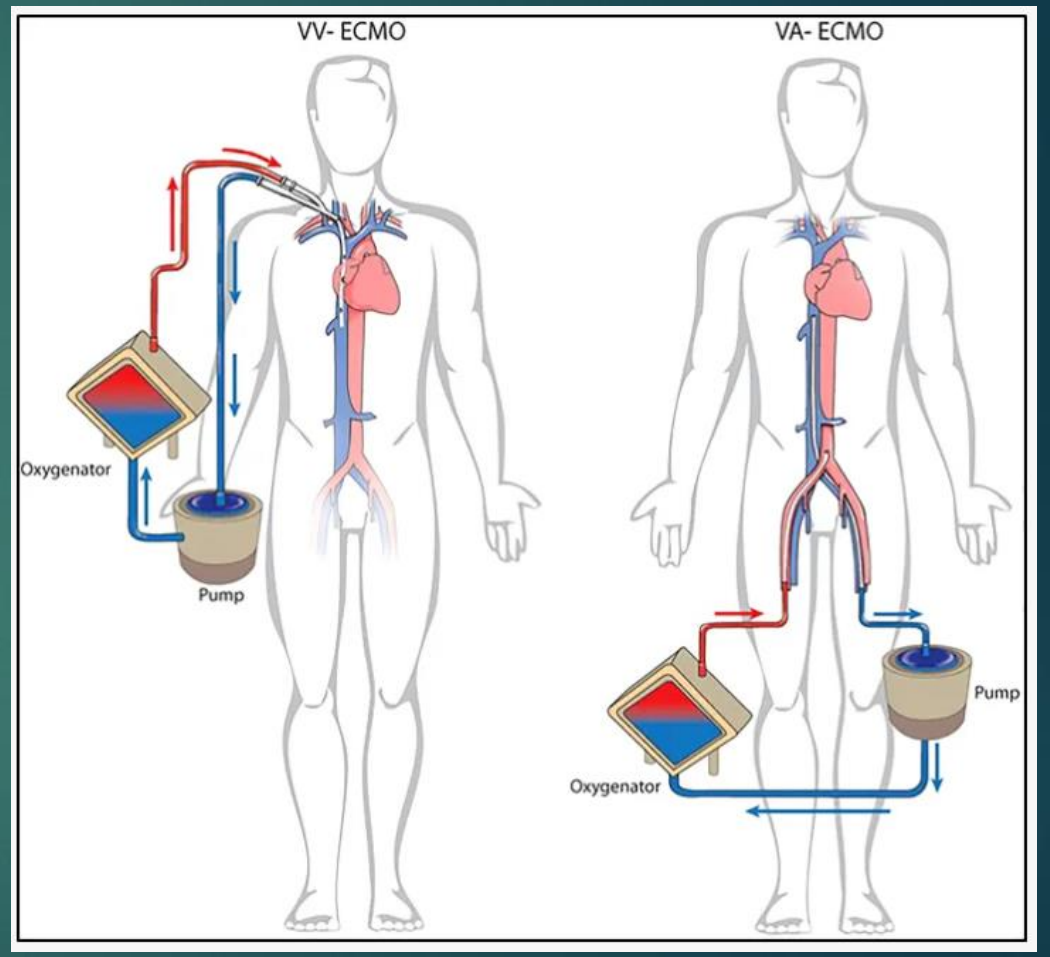
- Specifically referring to VV-ECMO for lung failure
- Controversial
- EOLIA (2018) found significant mortality benefit
  - Lots of cross over in the trial, challenging to generalize
  - Definite improvement in 60 day mortality
    - Later mortality targets were not significantly improved, though extensively debated
  - Mean age was in the 50s
  - No specific upper limit, but significantly worsened outcomes over 70

Extracorporeal Membrane Oxygenation (ECMO)

- ECMO centers generally have better outcomes due to larger teams, supplies, and more experience with severe ARDS, regardless of ECMO use
- In San Diego, patients with single organ failure ARDS < 60 years of age should be seriously considered to start ECMO

VV vs VA ECMO

- VV supports oxygenation only while VA supports both oxygenation and circulation
  - VA can be used for either lung failure or heart/lung failure
- Increasingly, can start at many hospitals (any at Scripps) with a plan to transfer to an ECMO center



Mangiameli G, Testori A, Cioffi U, Alloisio M and Cariboni U (2022) Extracorporeal membrane oxygenation support in oncological thoracic surgery. Front. Oncol. 12:1005929. doi: 10.3389/fonc.2022.1005929

- Questions?