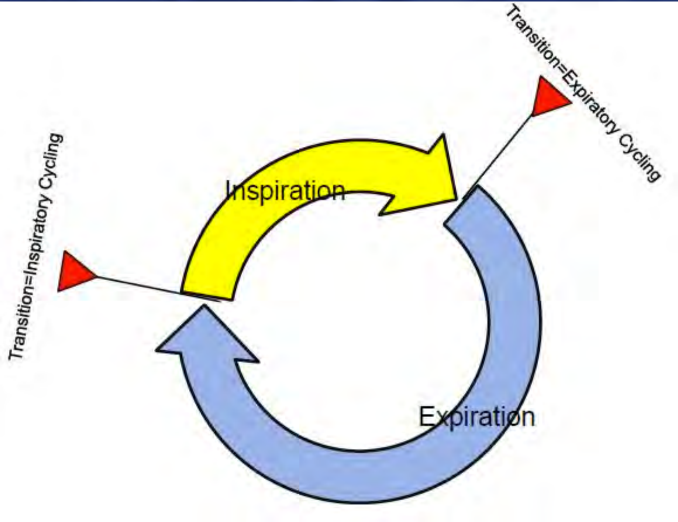
Mechanical Ventilation

University of Florida
Department of Anesthesiology
Anesthesiology / Critical Care Clerkship

Basic Physiology—Part 1

- Respiratory Cycle
- Oxygenation
- Ventilation
- Static lung volumes

Respiratory Cycle



- Inhalation & Exhalation
- Ingress & Egress
- But…
- Oxygenation & Ventilation
  - This Division has the Greatest utility
    - Breaking down problems
    - Implementing interventions
  - Any time there is uncertainty start here

Oxygenation

- How can we ascertain success?
  - Arterial Blood Gas (Abg)
    - PaO2
    - Reveals blood that enters trachea and diffuses into blood
    - Alveolar Gas Equation
      - P(A)O2 = FiO2 (Patm – Ph2o) – PCO2/RQ
        - » Alveolar gas = Ingress (O2) – Egress (CO2)
        - » Respiratory Quotient (RQ)
          - CO2 produced per O2 metabolized = 0.8
          - Depends on diet and metabolism
      - (A-a)gradient tells you oxygenating capability

Alveolar Gas Equation

$$P_{A_{O_2}} = P_{I_{O_2}} - \frac{P_{a_{CO_2}}}{R}$$

$$P_AO_2 = F_iO_2(P_{atm} - P_{H_2O}) - \frac{P_aCO_2}{0.8}$$

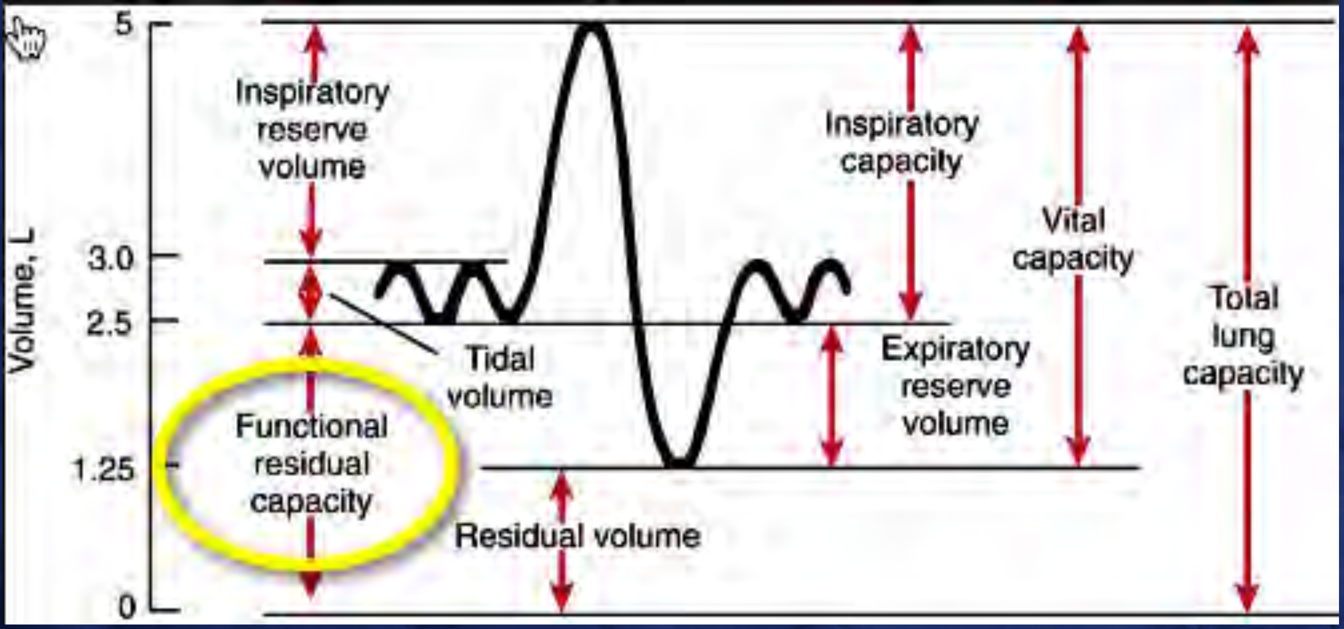
Oxygenation

- Can we tell success with SpO2?
  - Only if patient is on Room Air
  - For example
    - 100% FiO2 could give you an PAO2 of 760mmHg if perfect
    - SpO2 is 100% so all looks good
      - Actual ABG PaO2 reveals 95-100mmHg
      - Thus (A-a) Gradient = 660mmHg
    - This is a limitation of pulse oximetry assessing oxygenation

Ventilation

– Minute Ventilation = Tidal Volume x Respiratory Rate
  - Ve = Vt x RR
- Success is revealed by CO_2
  – High CO_2 = Hypoventilation
  – Low CO_2 = Hyperventilation
  – Respiratory rate?
    - NO…can be tachypnic and hypoventilating
    - Only moving dead space gas
    - Consider breathing through a long snorkel:
      – Only small amount of each breath reaching gas exchange

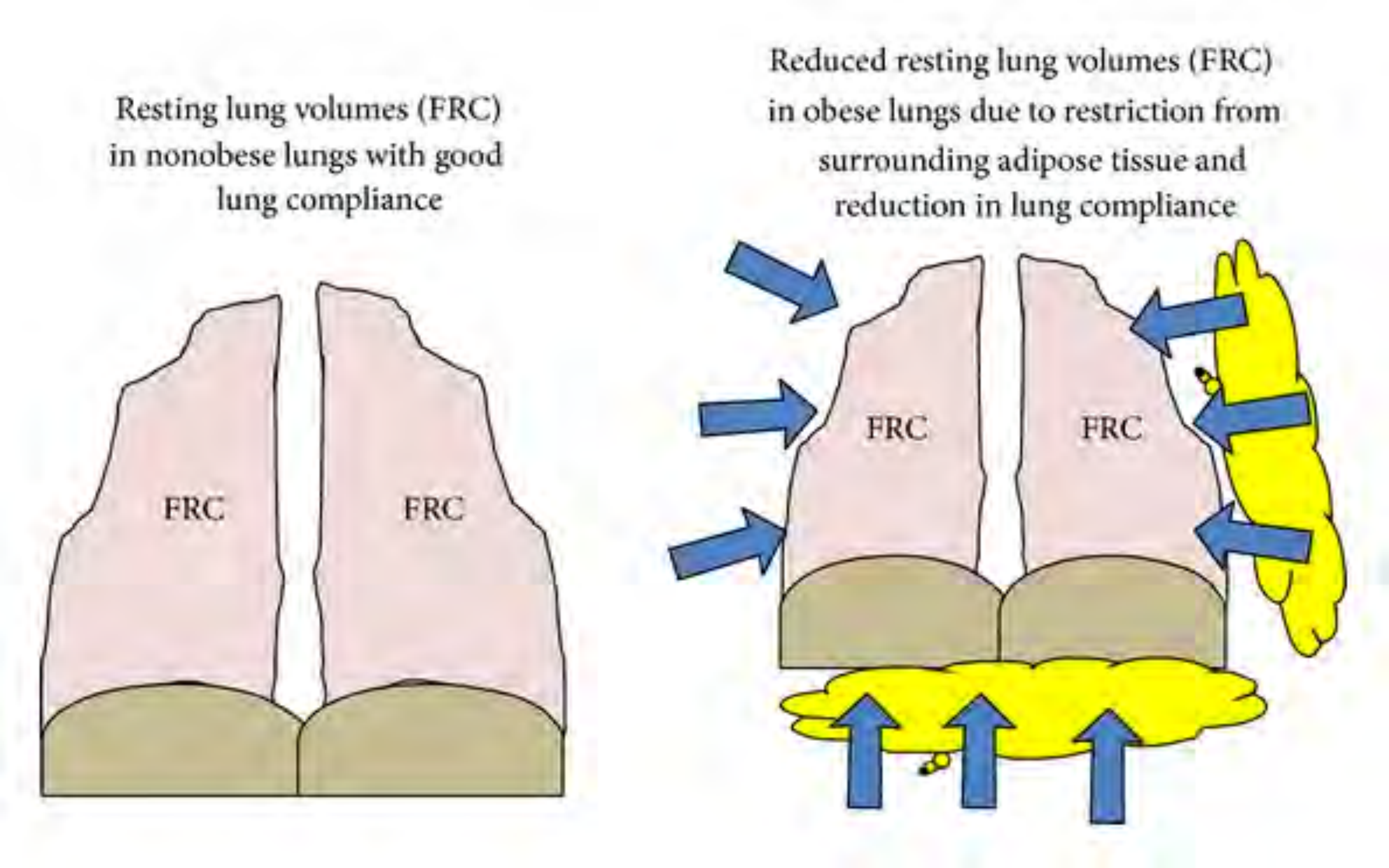
Static Lung Volumes



Functional Residual Capacity

- Residual Volume + Expiratory Reserve Volume
- Equilibrium of opposing forces
  - Chest Wall (expanding) + Lung Parenchyma (collapsing)
  - Forces are idiosyncratic
    - Chest wall: Obesity, pregnancy, paralysis, body position
    - Lung parenchyma: emphysema, ARDS,

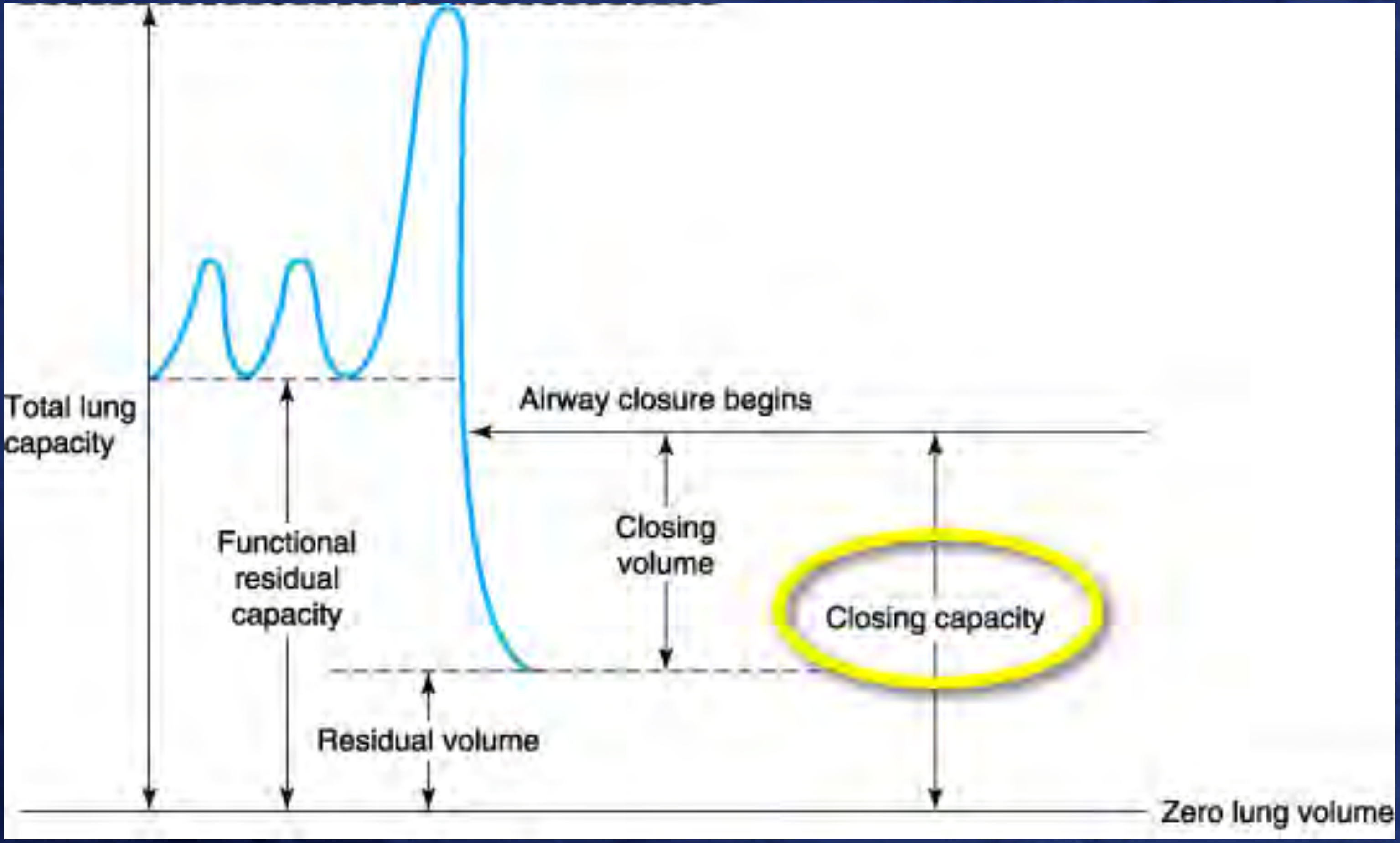
Functional Residual Capacity



Functional Residual Capacity

- Significance…
  - Consider FRC as a Reservoir
  - Normally filled with 21% oxygen and 78% nitrogen
  - Can De-Nitrogenate (i.e. Pre-oxygenate)
    - Now filled with 100% oxygen
    - Creates time for airway instrumentation
    - May manipulate FRC to improve safety profile

Closing Capacity



Closing Capacity (CC)

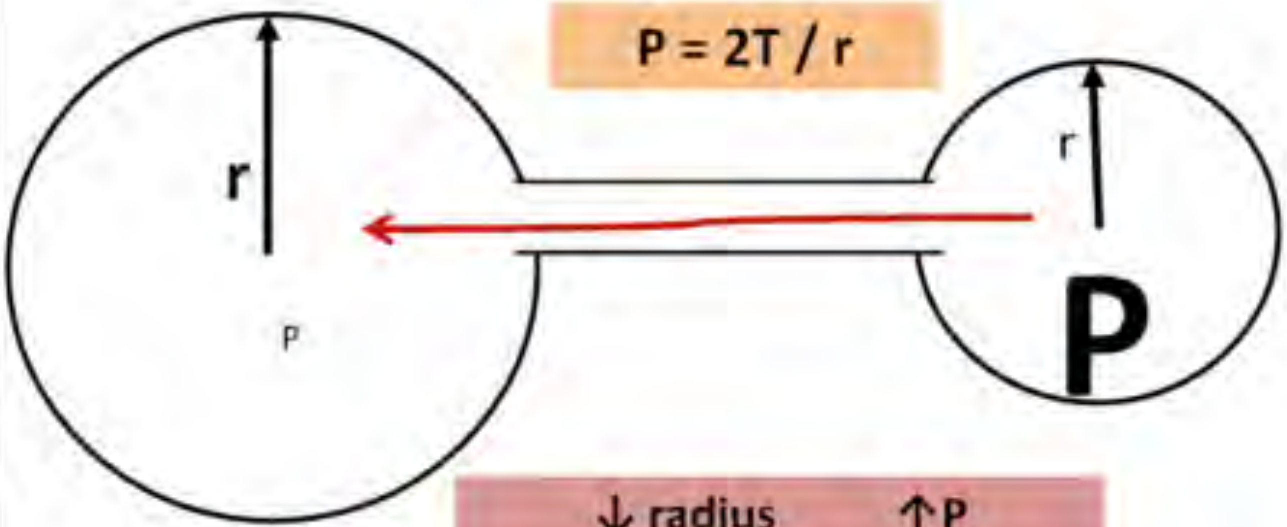
- CC

  = Residual Volume + Closing Volume

- Alveoli Collapse at the CC
  – Law of Laplace
  – Pressure = 2 x t /r
    - Surface tension (t) reduced by surfactant
    - Radius inversely impacts airway closure

Laplace's Law

Two bubbles with same surface tension , T, but different radii



↓ radius	↑P
↑ radius	↓P

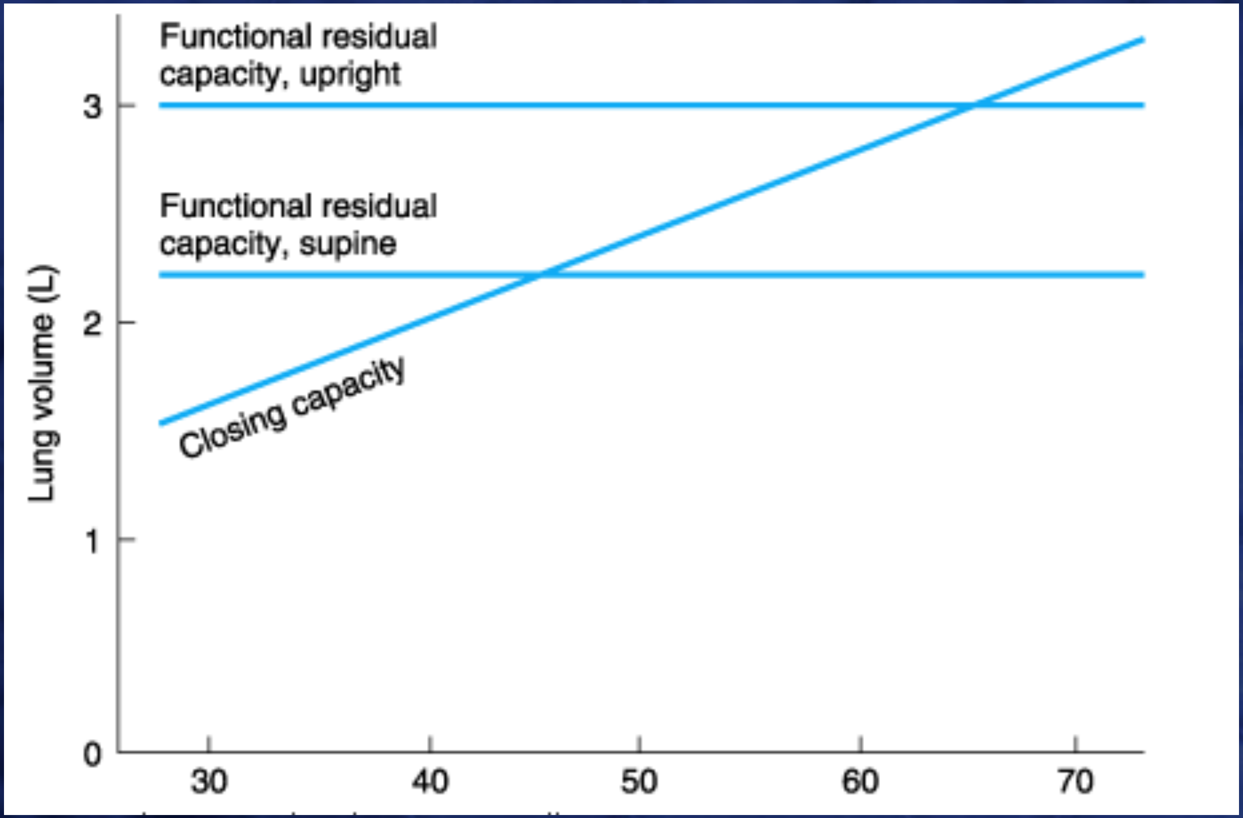
What happens if these two are interconnected?

Pressure Gradient exists between the two---- Flow would occur from small bubble to the larger one

Closing Capacity (CC)

- CC normally less then FRC so alveoli remain open
- Dependent of:
  - Age
  - Body position
  - pathology

Closing Capacity (CC)



Lung Volumes and Capacities

Measurement	Definition	Average Adult Values (mL)
Tidal volume (V_T)	Each normal breath	500
Inspiratory reserve volume (IRV)	Maximal additional volume that can be inspired above V_T	3000
Expiratory reserve volume (ERV)	Maximal volume that can be expired below V_T	1100
Residual volume (RV)	Volume remaining after maximal exhalation	1200
Total lung capacity (TLC)	RV + ERV + V_T + IRV	5800
Functional residual capacity (FRC)	RV + ERV	2300

Basic Physiology—Part 2

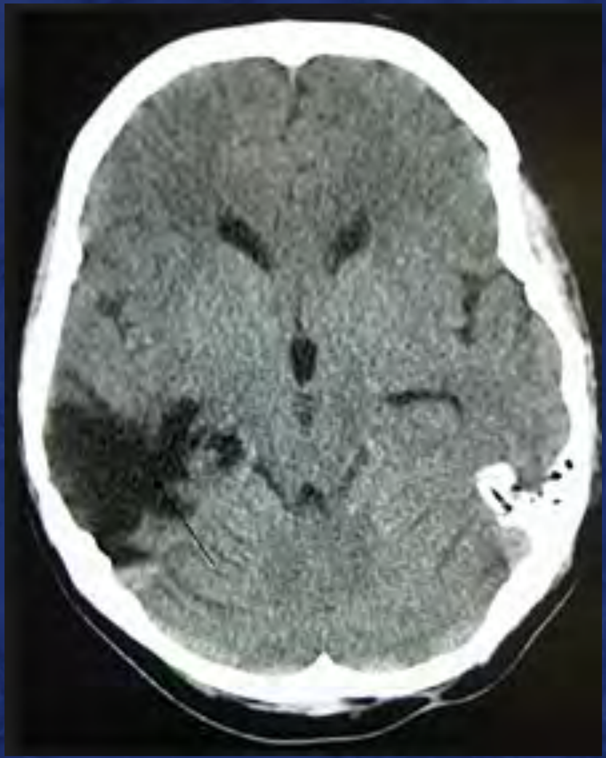
- Indications for Mechanical Ventilation
  - Ventilation Failure
  - Oxygenation Failure
  - A somewhat artificial division
    - One type of failure may involving both
    - But helps to compartmentalize and remember

Ventilation Failure

- Neurologic Disease
- Muscular Disease
- Anatomic Disease

Neurologic pathology

- Central Pathology
  - Sedation
    - Benzodiazepines
    - Opiates
  - Stroke
  - Trauma
    - Traumatic Brain Injury

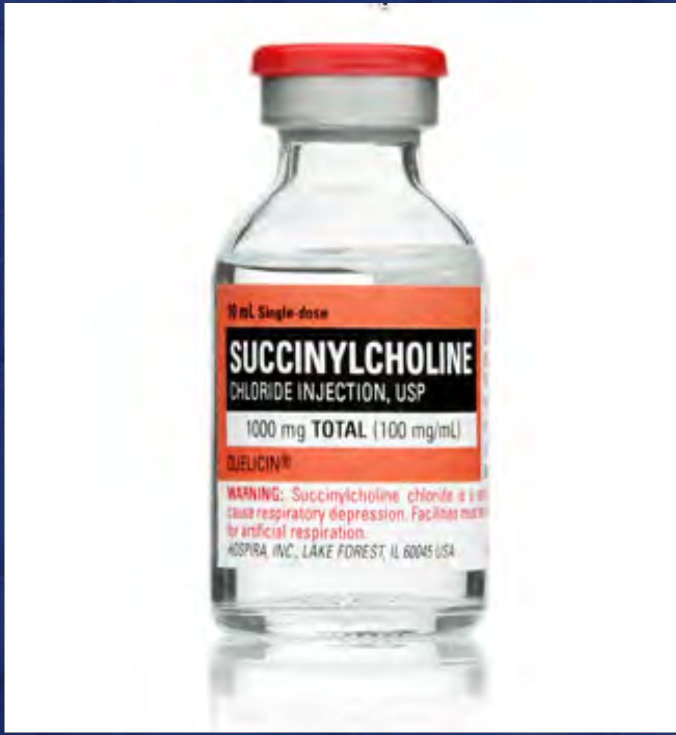


Neurologic Pathology

- Spinal cord pathology
  - Trauma
  - Virus
  - Stroke

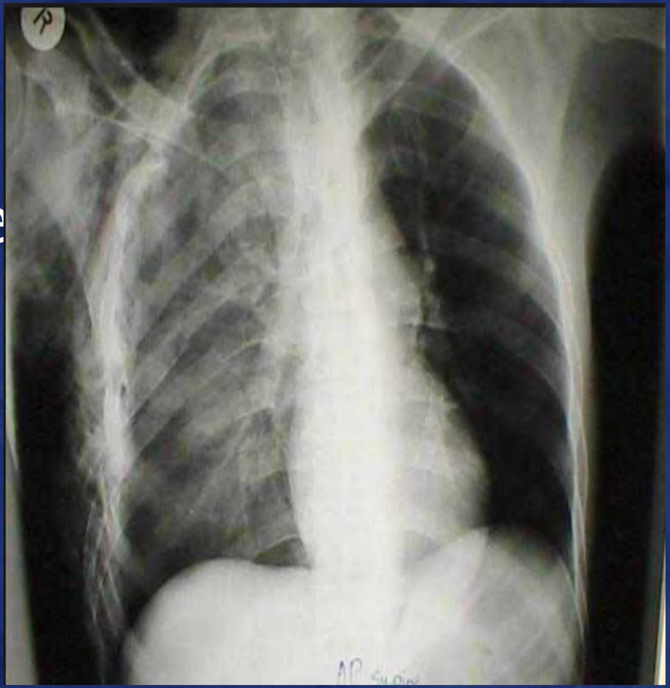
Neurologic Pathology

- Peripheral Nerve pathology
  - Neuromuscular relaxants
  - Guillain-Barre syndrome



Anatomic Pathology

- Chest Wall pathology
  - Flail chest
  - Congenital Diaphragmatic he
  - Kyphoscoliosis
- Pleural injury
  - Pneumothorax
  - Hemothorax
  - Pleural effusions

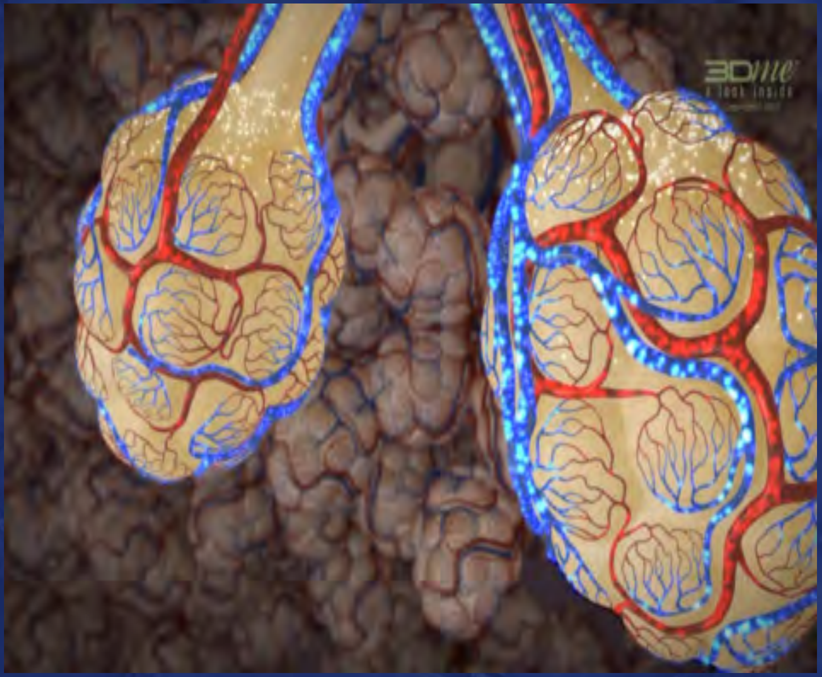


Anatomic Pathology

- Airway Pathology
  - Burn
  - Epiglottis
  - Bronchospasm
  - Foreign body

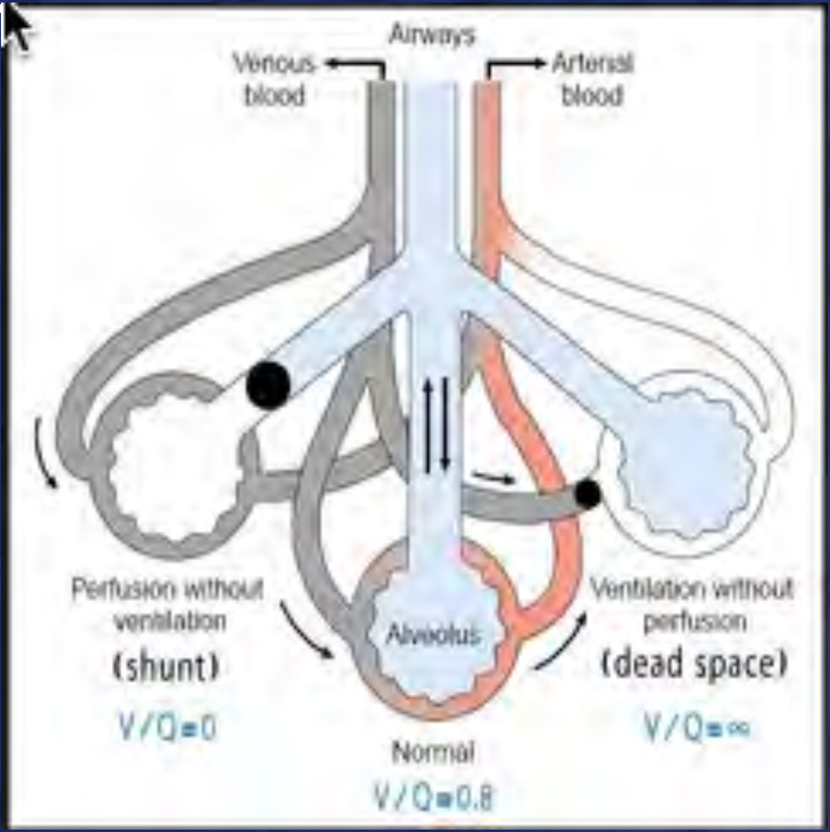
Oxygenation Failure

- Gas Exchange Problem
  - V / Q Mismatch
  - Diffusion abnormality
  - VO2/ DO2 imbalance
  - FiO2



Ventilation / Perfusion Mismatch

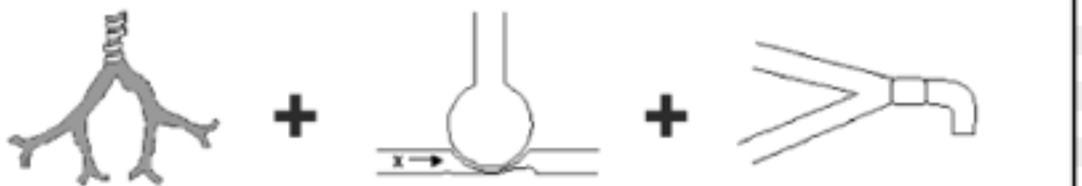
- Matching is a spectrum
  - Dead space
  - V / Q = 1:1
  - Shunt



Dead Space

- Ventilated areas which do not participate in gas exchange

Total Deadspace = Anatomic + Alveolar + Mechanical



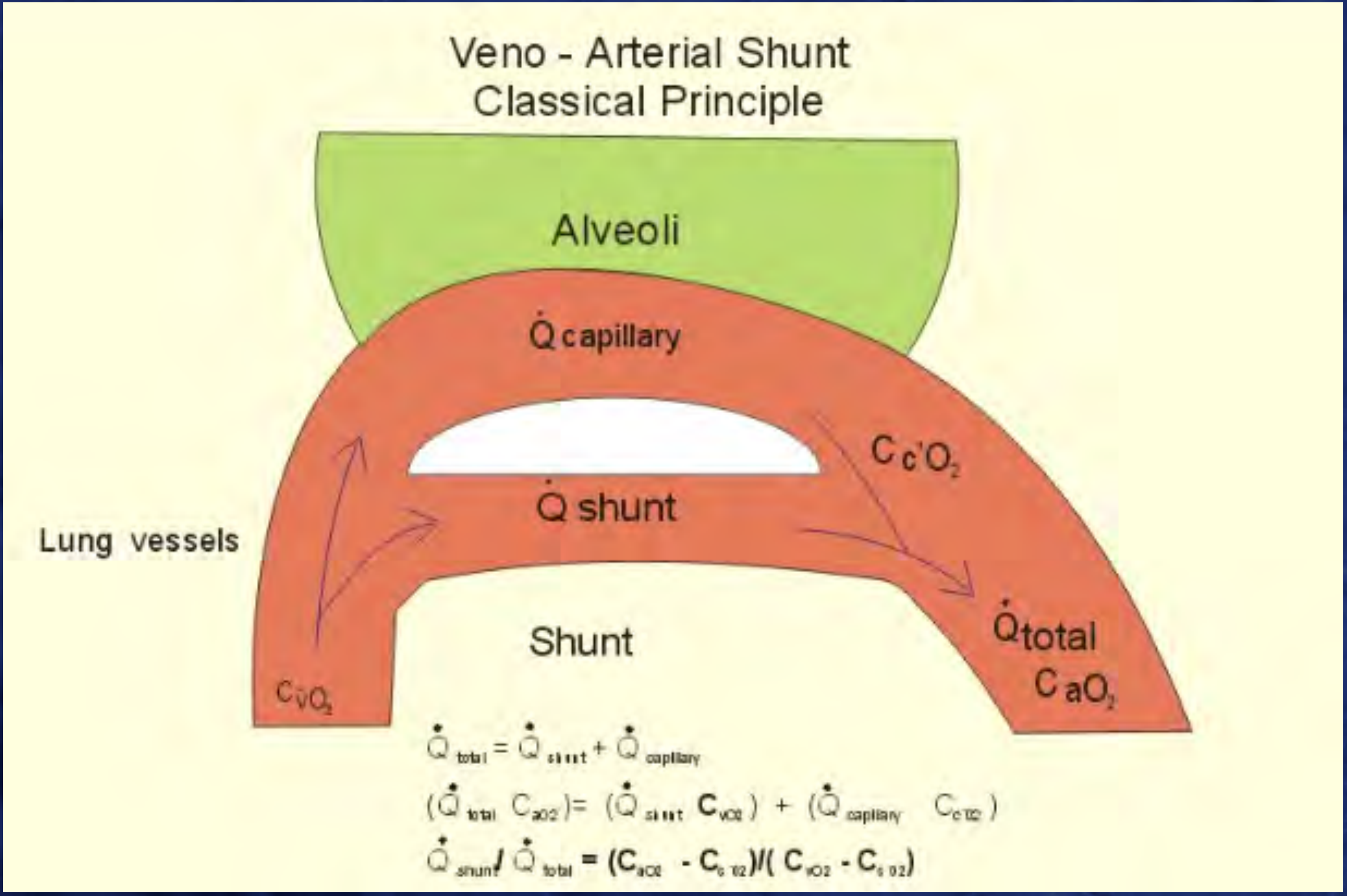
Anatomic Deadspace:	Alveolar Deadspace:	Mechanical Deadspace:
airways leading to the alveoli	ventilated areas in the lungs without blood flow	artificial airways including ventilator circuits

Dead space equation

$$\frac{V_d}{V_T} = \frac{P_{A_{CO_2}} - P_{\overline{E}_{CO_2}}}{P_{A_{CO_2}}}$$

$$V_d = \frac{P_{a_{CO_2}} - P_{\overline{E}_{CO_2}}}{P_{a_{CO_2}}} \bullet V_T$$

Shunt



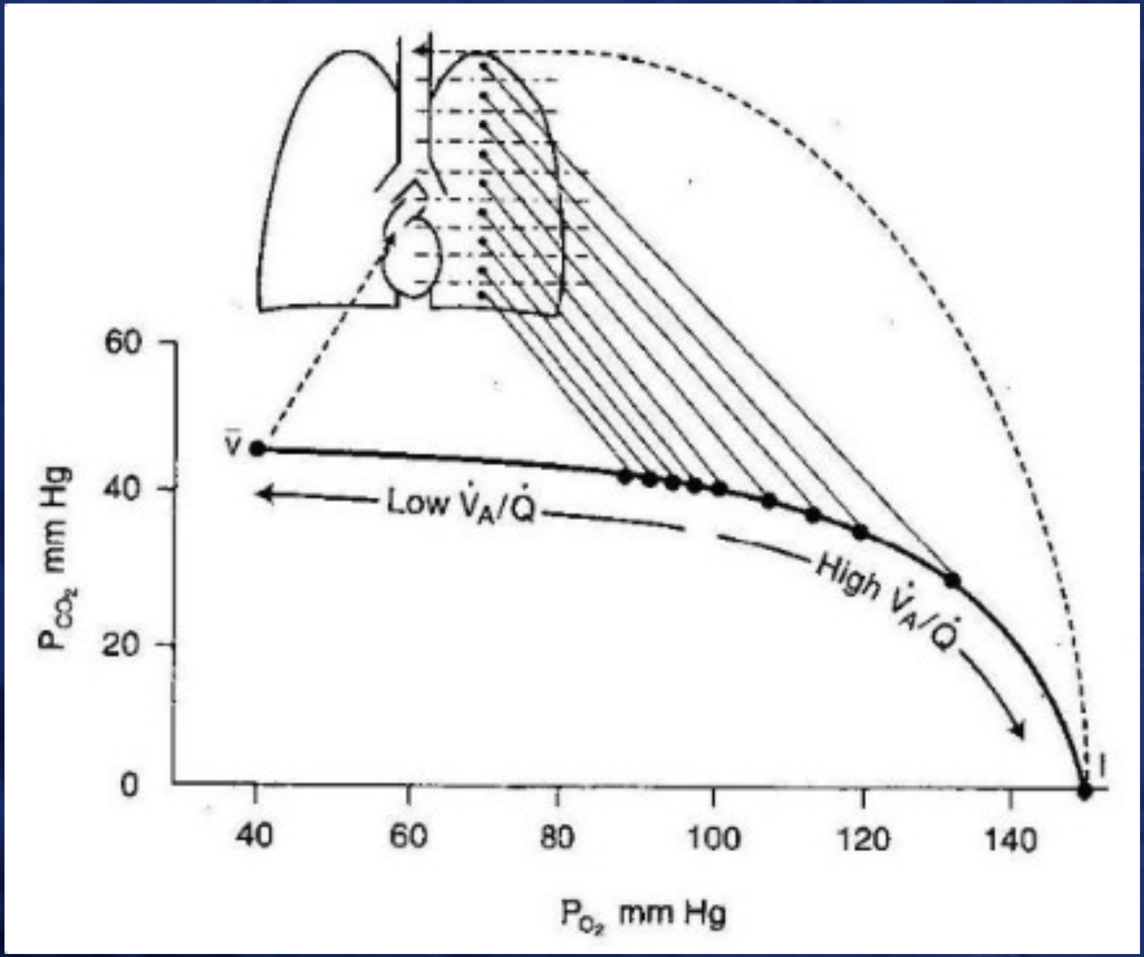
Veno - Arterial Shunt
Classical Principle
Alveoli
Q capillary
C c'O2
Q shunt
Lung vessels
Shunt
Q total
C aO2
C v̄O2
Q total = Q shunt + Q capillary
(Q total C aO2) = (Q shunt C vO2) + (Q capillary C c'O2)
Q shunt / Q total = (C aO2 - C c'O2)/(C vO2 - C c'O2)

Shunt

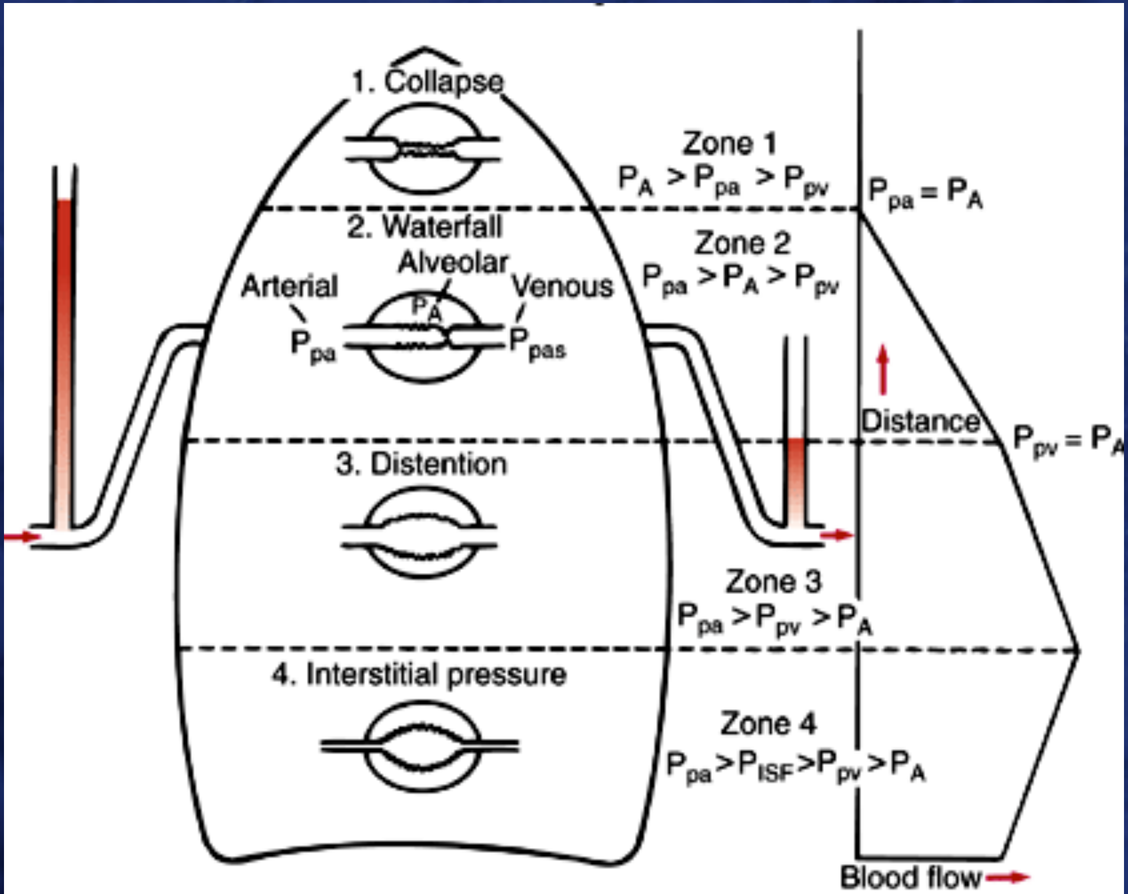
Magnitude of pulmonary shunts

1. Normal shunt = 2-5%
2. Shunt over 5% could indicate problem
3. Shunt over 15% indicates pathological problem
4. Shunt increases with age

V/ Q Matching Spectrum

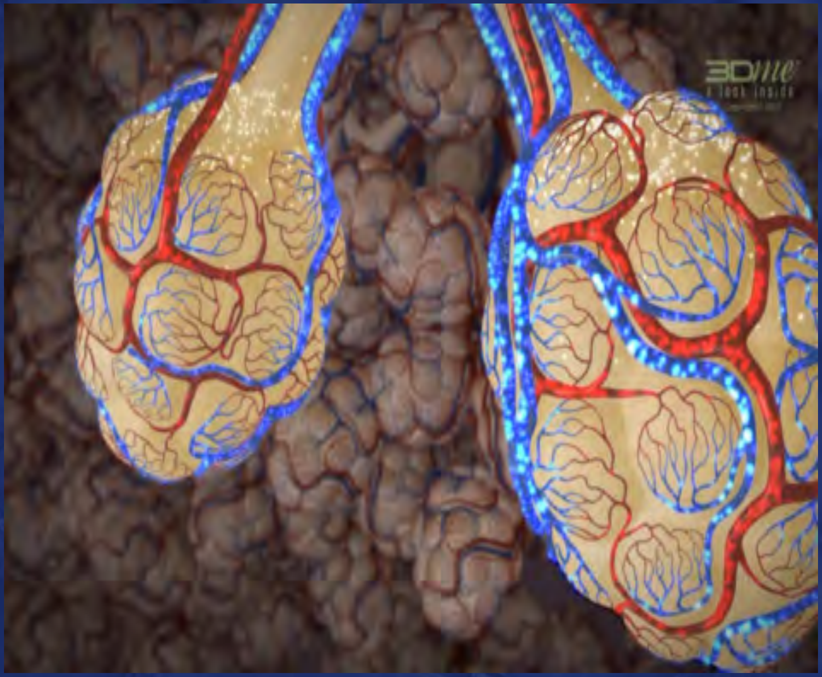


V / Q Matching : West Zones



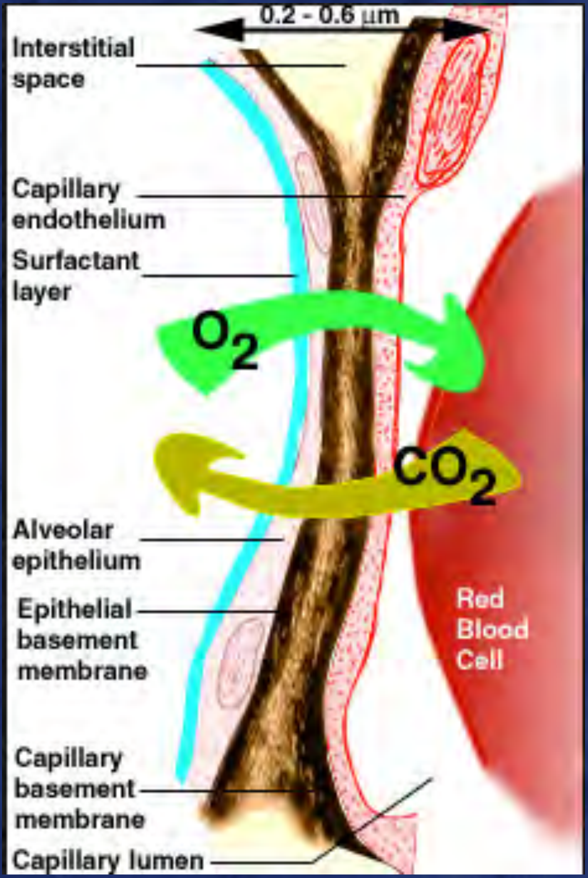
Oxygenation Failure

- Gas Exchange Problem
  - V / Q Mismatch
  - Diffusion abnormality
  - VO2/ DO2 imbalance
  - FiO2



Diffusion Abnormality

- Gas Exchange Problem
- Evaluated with DLCO
- Pathology:
  - Emphysema
  - Idiopathic Pulmonary fibrosis
  - Sarcoidosis
  - Pulmonary Hypertension
  - Interstitial Pneumonitis
  - Pulmonary Vasculitis

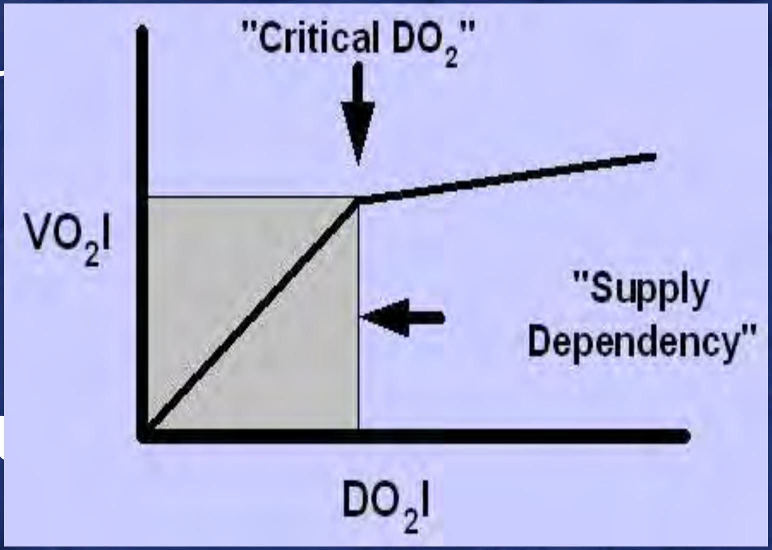


Oxygenation Failure

- Gas Exchange Problem
  - V / Q Mismatch
  - Diffusion abnormality
  - VO2/ DO2 imbalance
  - FiO2

VO2 / DO2 Imbalance

- Oxygen consumption exceeds Oxygen Delivery
- Causes:
  - Decreases in Cardiac Output
    - Preload
    - Heart rate
    - Contractility
  - Increases in Oxygen Extraction
    - Hypermetabolic states
    - Sepsis



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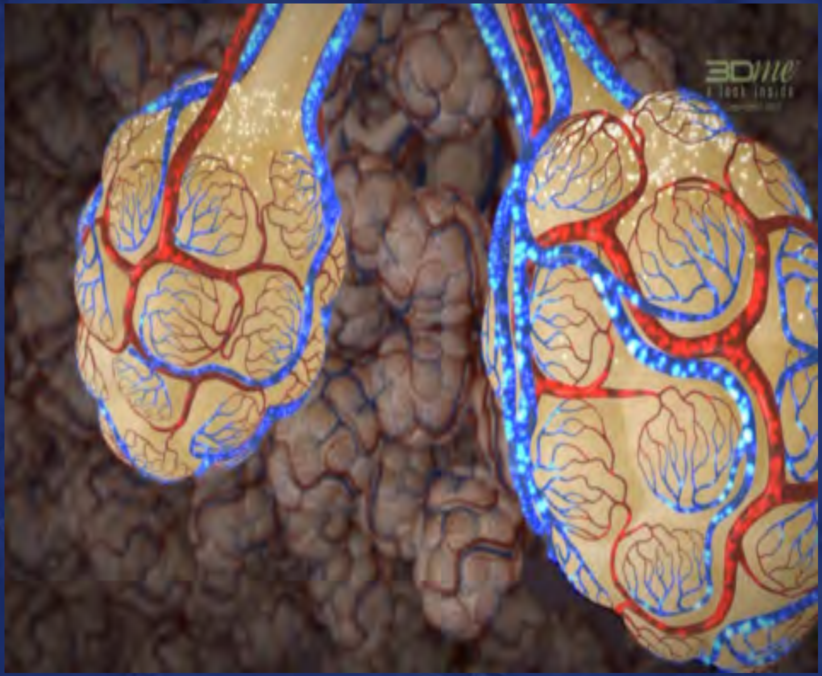


FiO2

- Inadequate oxygen concentration
  - Requires elevated concentrat
  - Change Barometric pressure
  - Oxygen displaced by other ga

Mechanical Ventilation

- Volume Controlled (ACV)
- Pressure Controlled (PCV)
- SIMV
- Pressure Support (PS)

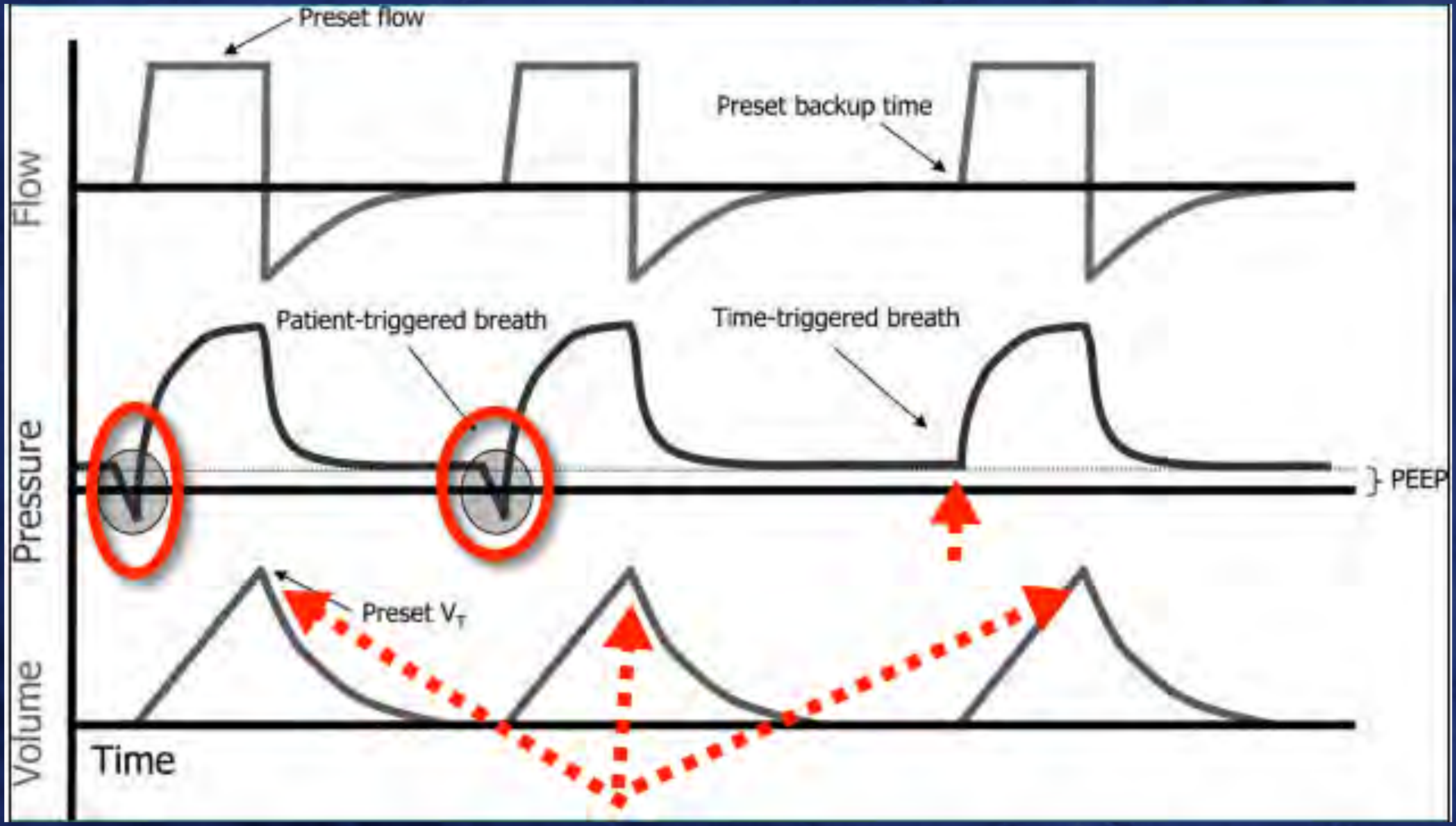
Volume Controlled Ventilation

- 2 forms :
  1. Assist-Control Ventilation
  2. Controlled Ventilation
- *Controlled Ventilation*
  - Provider dials in desired tidal volume & respiratory rate
  - Settings delivered regardless of effort (no additional breaths permitted)
  - Gas flows to patient to deliver preset tidal volume
    - May occur despite Peak Airway Pressures

Volume Controlled Ventilation

- *Assist-Controlled Ventilation*
- Vt and RR determined by provider
- Any patient respiratory effort
  - triggers preset tidal volume
  - Defaults to initial settings if no effort attempted
  - Provider selects trigger threshold sensitivity

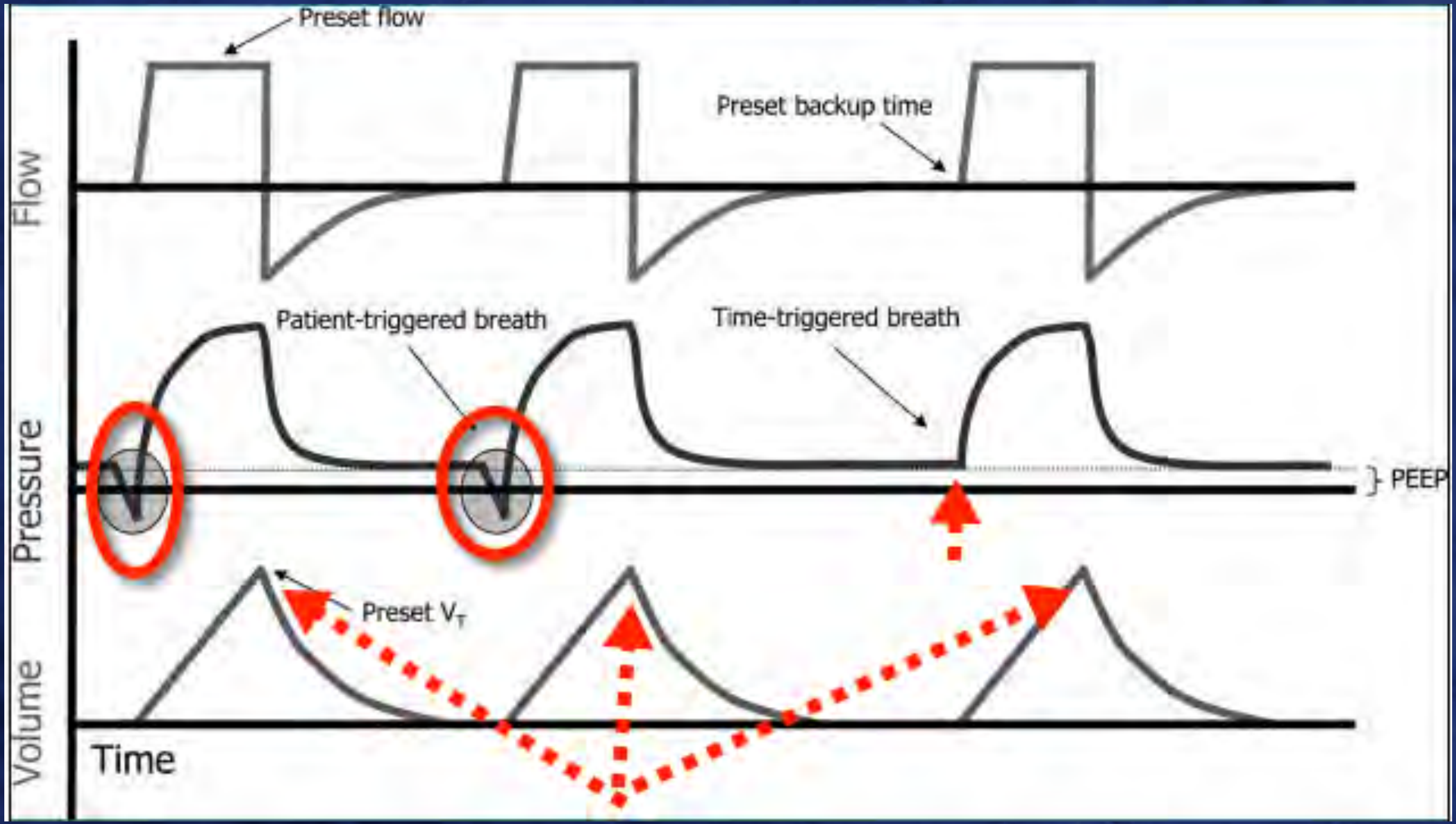
Controlled Ventilation



Controlled Ventilation

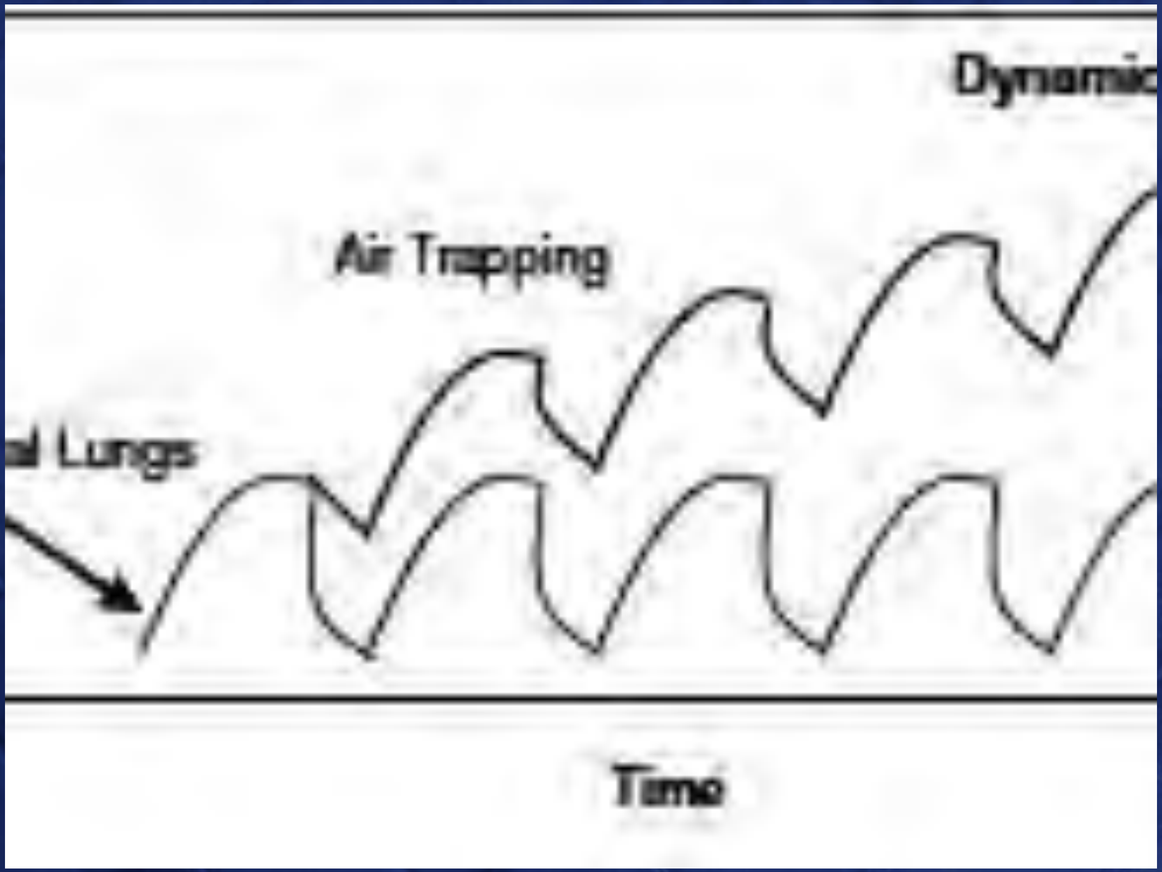
- Previous cartoon (to be reviewed on next slide)
  - Circles represent areas of initiated breaths (assisted)
  - No Effort follows 2 assisted breaths
  - Each Breath exactly same volume delivered

Controlled Ventilation



Volume Controlled

- Excessive Breaths can lead to “breath-stacking”
  - Also called Auto-PEEP
  - Can obstruct preload or cause pneumothorax
  - Causes increase Work of Breathing
  - Risk of significant Patient-ventilator Dysynchrony



Breath-Stacking

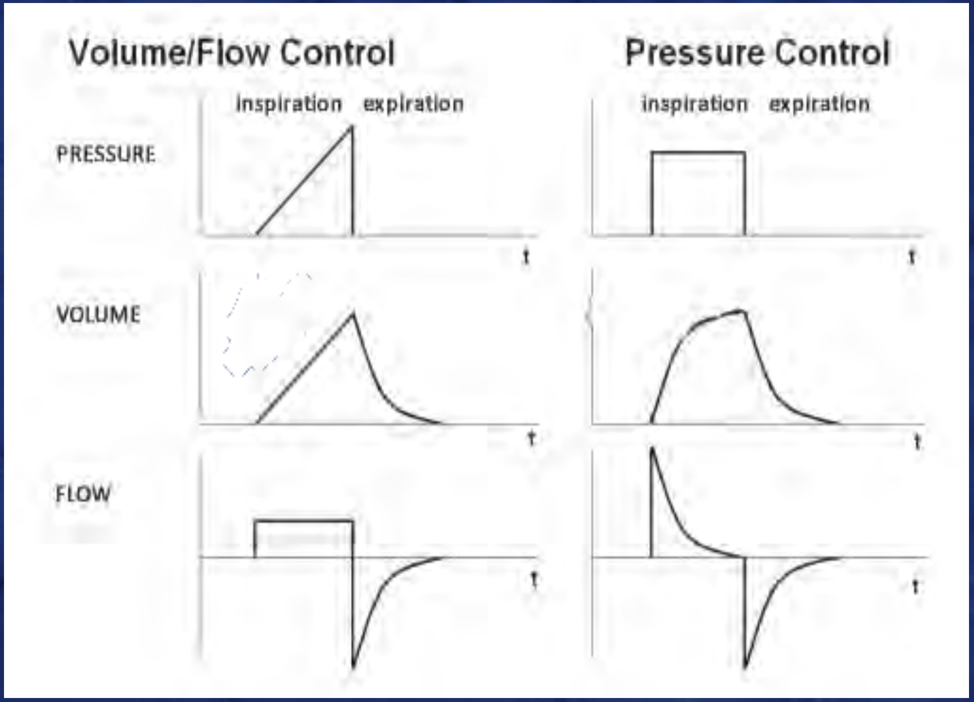
Not Enough time allowed for complete exhalation.
Each inspired breath ”Stack” on top of the previous breath.
Significant risk of hemodynamic changes and barotrauma (Ptx).

Pressure-Controlled Ventilation

- Provider dials in RR and fixed Pressure to deliver breath
- Volume of each Breath varies due to different pulmonary mechanics:
  - Different from person to person
  - Different in same person but different scenarios
    - Patient position, muscle relaxation, abdominal pressures,…
  - Breath delivery
    - Breath filling pressure maintained at same level
    - Decelerating flow wave allows for large tidal volumes

Pressure-Control

- Compare to Volume-Controlled:
- 1. Constant pressure level delivered
- 2. Volume augmentation
- 3. Decelerating gas flow

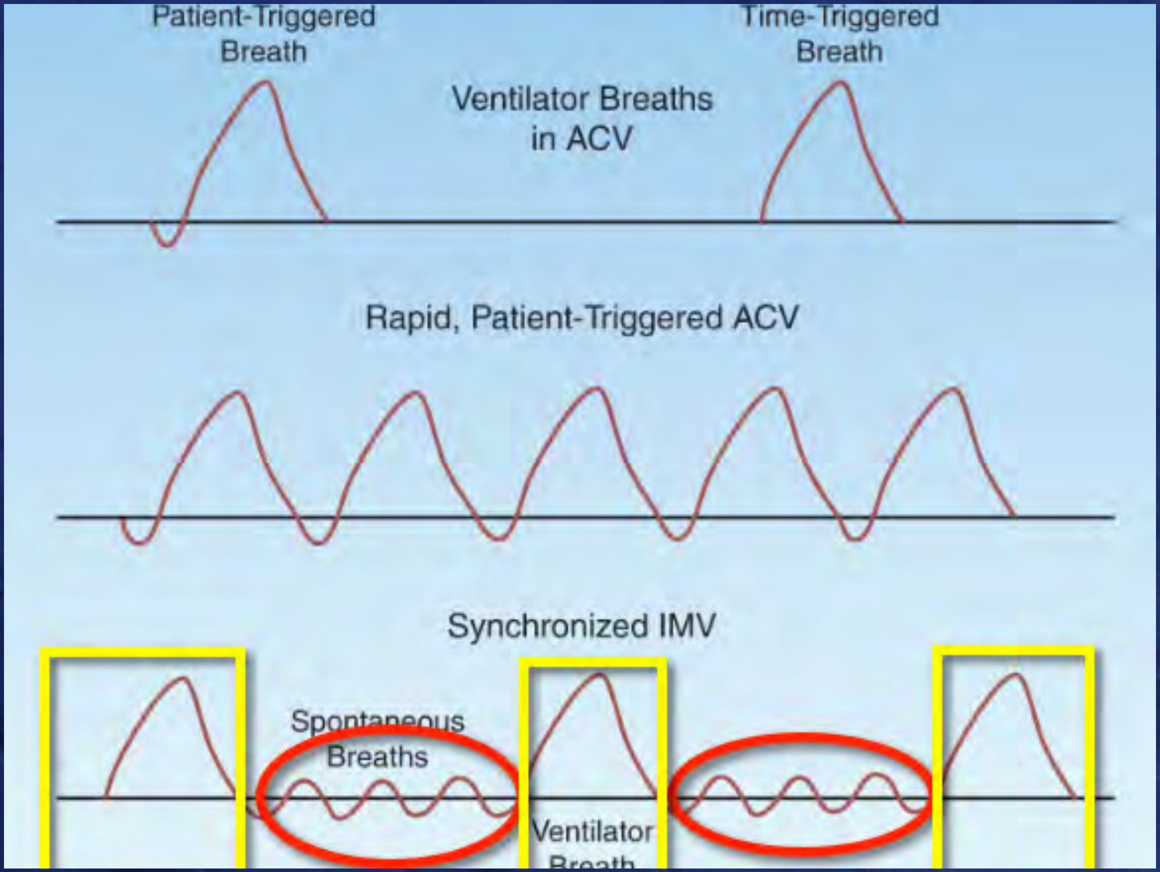


Pressure-Controlled Ventilation

- Advantages
  - Less likelihood of barotrauma
  - Greater Patient-Ventilator synchrony
  - Larger tidal volumes with smaller Driving pressure

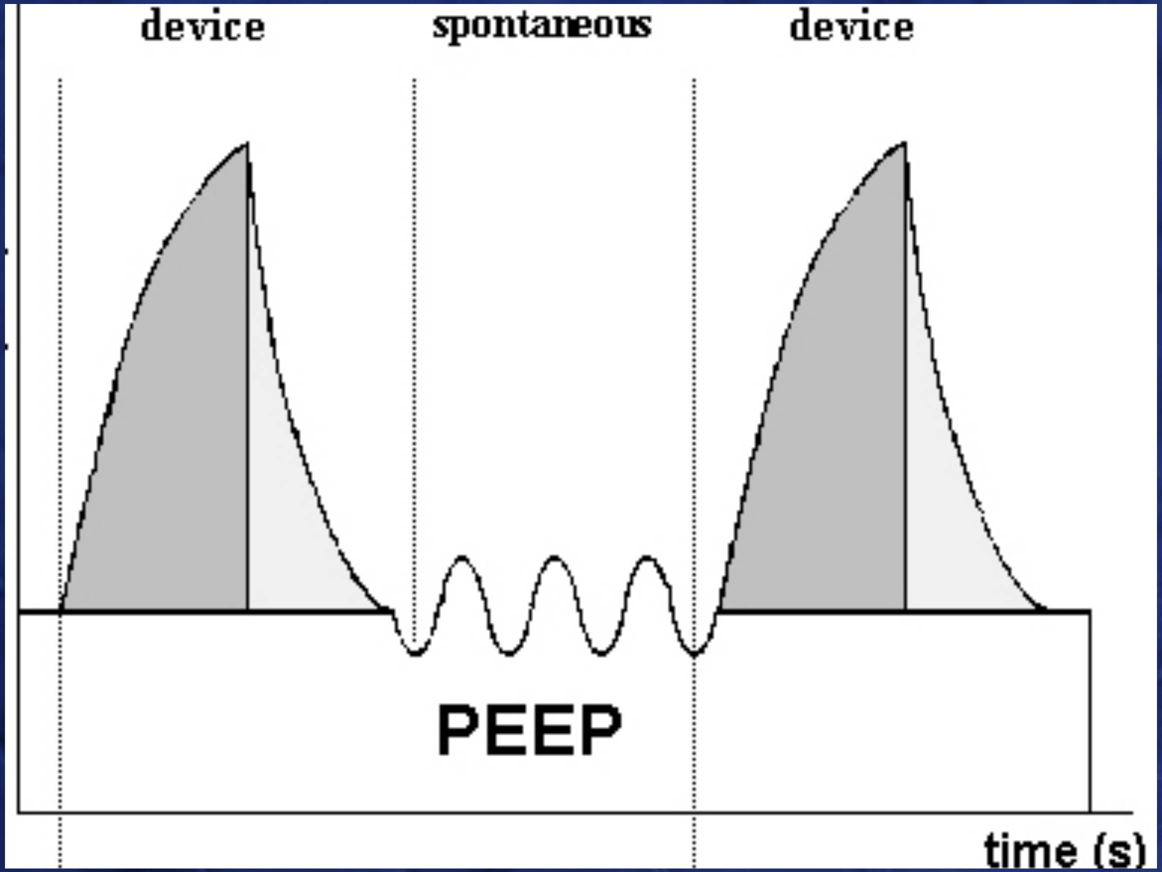
SIMV

- Synchronized-Intermittent Mandatory Ventilation
- Breaths are delivered in a preset RR and volume
- Patient can breath independently between breaths
  - No additional effort is provided for extra breaths
  - Patient maintains some independence in ventilation
  - Used to wean patient from ventilator
    - Progressively dial back mandatory breaths
    - Allow progressively more spontaneous ventilation



SIMV

Ovals reveal unsupported additional breaths.
Squares show preset respiratory rate and tidal volumes.
Top reveals Controlled ventilation without additional triggering.
Middle shows additional triggering leading to rapid RR.



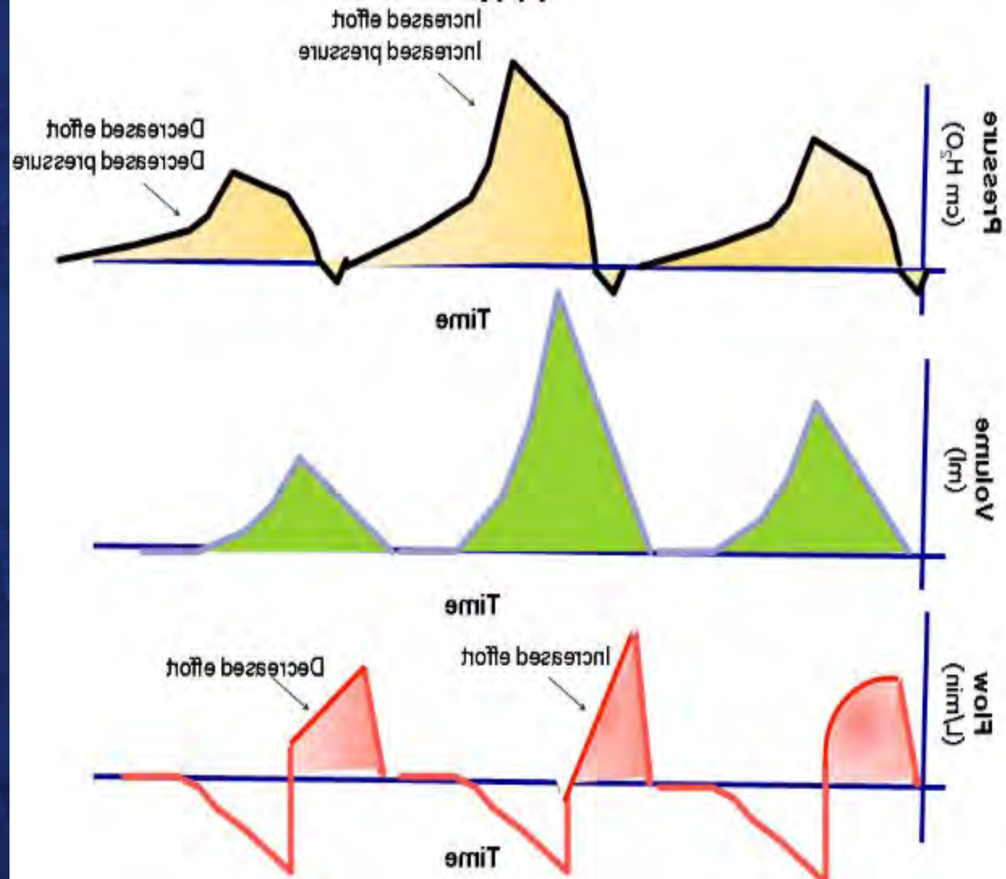
SIMV

Can augment spontaneous breaths with pressure support.

Can add PEEP to the system as well to assist oxygenation.

Pressure Support Ventilation

- Patient initiates Every breath
- Ventilator delivers support with preset pressure value
- Patient regulates
  - Own respiratory rate
  - Own tidal volume
- Changes in Pulmonary Mechanics or patient effort
  - Affects tidal volume and RR



Pressure Support Ventilation

Increasing effort or Pressure support will increase delivered volume.
Decreasing effort or Pressure support will decrease delivered volume.

PEEP—Oxygenation Tool

- Positive End-Expiratory Pressure
- Pressure in the lungs (above Atm) that exists in the lungs after expiration
- Coupled with FiO_2 for tools to improve oxygenation
- Amount is dialed in by provider to mitigate atelectasis
  - Improves V / Q matching
  - Can reduce the rapid opening and closing of alveoli
  - ARDS net protocol to help oxygenation in next slide

FiO2 & PEEP to treat ARDS

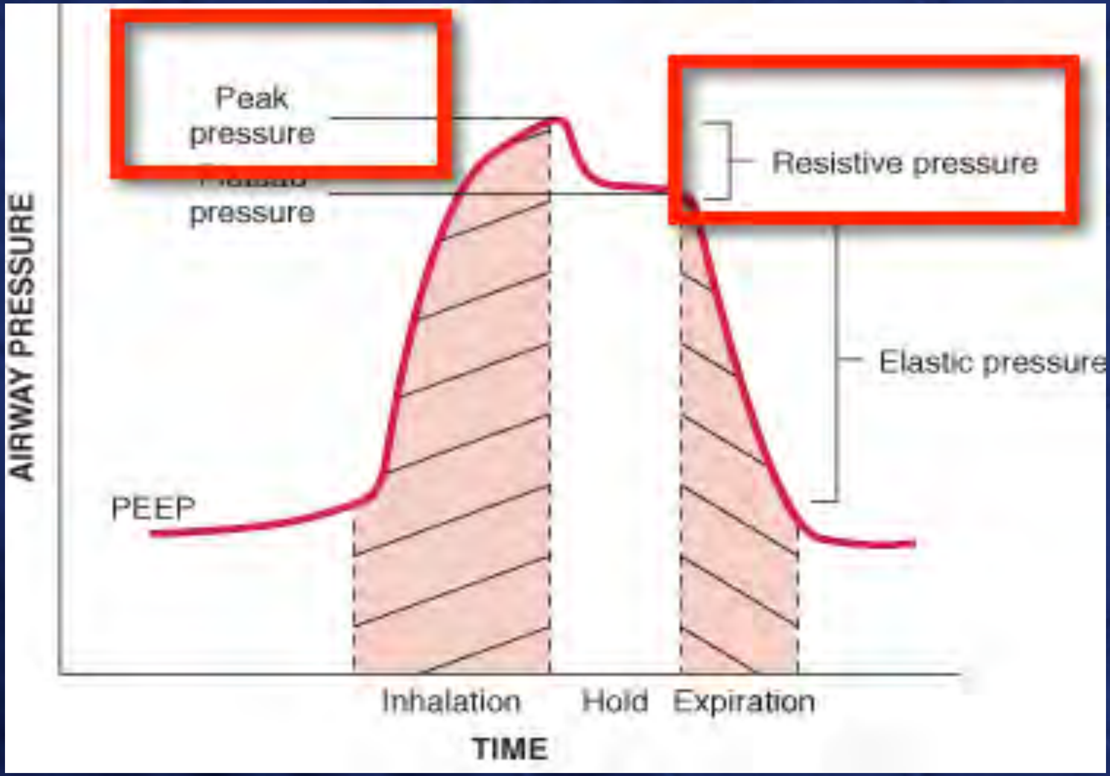
Conservative approach:																	
FiO_2	0.30	0.40	0.40	0.50	0.50	0.60	0.70	0.70	0.70	0.80	0.90	0.90	0.90	1.0	1.0	1.0	1.0
PEEP	5	5	8	8	10	10	10	12	14	14	14	16	18	18	20	22	24
Aggressive approach:																	
FiO_2	0.30	0.30	0.40	0.40	0.50	0.50	0.60	0.60	0.70	0.80	0.80	0.90	1.0	1.0			
PEEP	12	14	14	16	16	18	18	20	20	20	22	22	22	24			

Monitoring Lung Mechanics

- Proximal Airway Pressures
  - Peak Inspiratory Pressure
  - Plateau Pressure

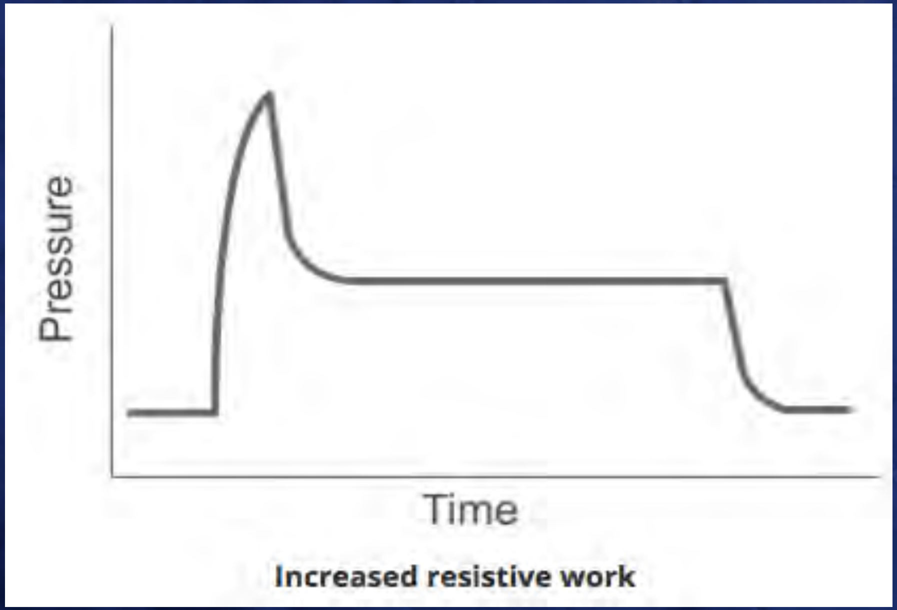
- Thoracic Compliance
  - Chest Wall compliance
  - Lung compliance

Proximal Airway Pressures (peak)



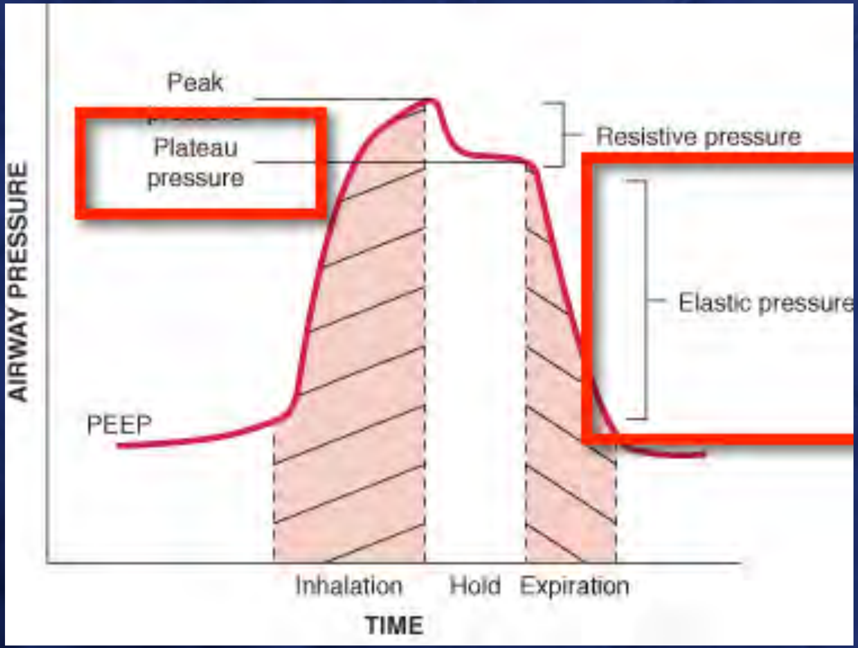
- Peak pressure
  - Pressure in lungs generated during inspiration
  - Combination of
    - Resistance in airway
    - Elastance of lungs
  - Ends with End-inspiration

Peak Airway Pressure



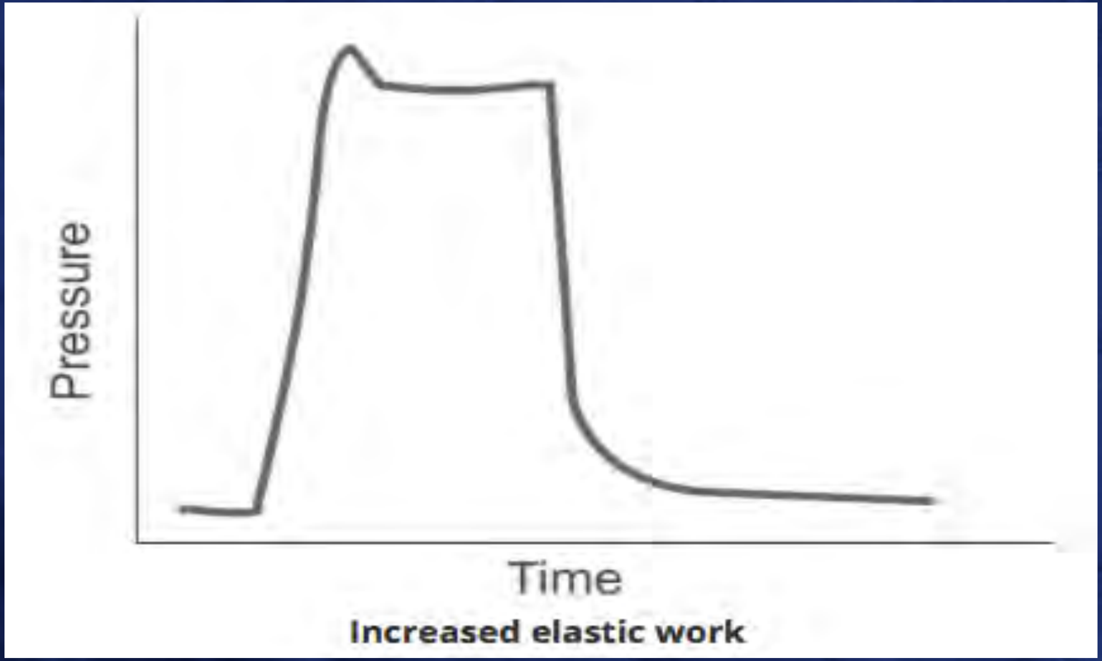
- Increased airway resistance
  - Airway obstruction
  - Bronchospasm
  - Circuit kinking
  - Endotracheal tube obstruction
  - anaphylaxis

Proximal Airway Pressures (plateau)



- Plateau pressure
- Pressure in the airway without any air movement
  - During inspiratory pause
- Determined by Compliance of lung
  - Inversely proportional to elastance

Plateau Pressure



- Increased Plateau pressure
  - Pneumothorax
  - Pneumonia
  - ARDS
  - Auto-PEEP
  - Obesity
  - Pulmonary fibrosis

Thoracic Compliance

- = Change in Volume/ change in Pressure (V/P)
- Inversely proportional to elastance
- Compliance can involve static or dynamic measurement
  - Cdyn = Vt / (PIP –PEEP)
    - Compliance measured during gas flow
    - PIP = peak inspiratory pressure
  - Cstat = Vt / (Pplt – PEEP)
    - Compliance measured without gas flow
    - Pplt = Plateau pressure

Thoracic Compliance

Lung compliance

- Involves lung parenchyma
- Fibrosis vs. Emphysema
- Blood and fluid volumes
- Surfactant deficiency
- pneumothorax

Chest Wall Compliance

- Involves muscles and fat
- Morbidly obese
- Large breast
- Muscle relaxation
- Positioning

THE END

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