## Introduction

- Indications
- Basic anatomy and physiology
- Modes of ventilation
- Selection of mode and settings
- Common problems
- Complications
- Weaning and extubation

## Indications

- **Respiratory Failure**
  - Apnea / Respiratory Arrest
  - inadequate ventilation (acute vs. chronic)
  - inadequate oxygenation
  - chronic respiratory insufficiency with FTT

## Indications

- **Cardiac Insufficiency**
  - eliminate work of breathing
  - reduce oxygen consumption
- **Neurologic dysfunction**
  - central hypoventilation/ frequent apnea
  - patient comatose, GCS $\leq$ 8
  - inability to protect airway

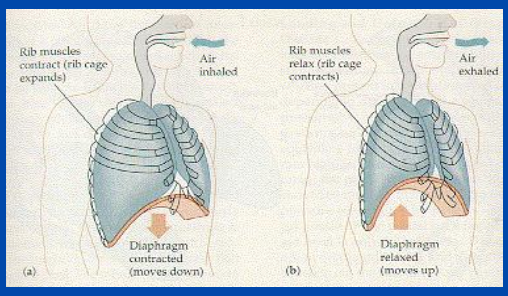
## Basic Anatomy

- Upper Airway
  - humidifies inhaled gases
  - site of most resistance to airflow
- Lower Airway
  - conducting airways (anatomic dead space)
  - respiratory bronchioles and alveoli (gas exchange)

## Basic Physiology

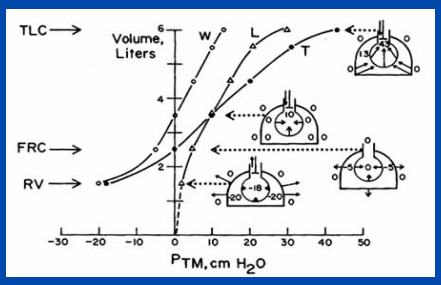
- Negative pressure circuit
  - Gradient between mouth and pleural space is the driving pressure
  - need to overcome resistance
  - maintain alveolus open
    - overcome elastic recoil forces
  - Balance between elastic recoil of chest wall and the lung

## Basic Physiology




http://www.biology.eku.edu/RITCHISO/301notes6.htm

## Normal pressure-volume relationship in the lung




http://physioweb.med.uvm.edu/pulmonary_physiology

## Ventilation

- **Carbon Dioxide**

  $PaCO_2 = k * \frac{\text{metabolic production}}{\text{alveolar minute ventilation}}$

Alveolar MV = resp. rate * effective tidal vol.

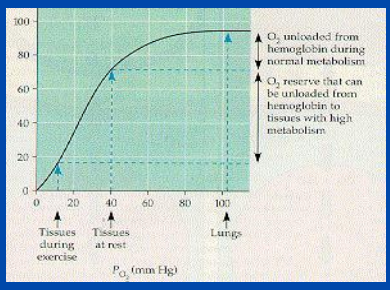
Effective TV = TV - dead space

Dead Space = anatomic + physiologic

## Oxygenation

- **Oxygen**:
  - Minute ventilation is the amount of fresh gas delivered to the alveolus
  - Partial pressure of oxygen in alveolus ($P_AO_2$) is the driving pressure for gas exchange across the alveolar-capillary barrier
  - $P_AO_2$ = ({Atmospheric pressure - water vapor} *$FiO_2$) - $P_aCO_2$ / RQ
  - Match perfusion to alveoli that are well ventilated
  - Hemoglobin is fully saturated 1/3 of the way thru the capillary

## Oxygenation

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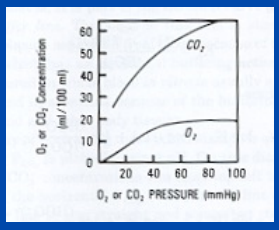
## $CO_2$ vs. Oxygen




## Abnormal Gas Exchange

- Hypoxemia can be due to:
  - hypoventilation
  - V/Q mismatch
  - shunt
  - diffusion impairments
- Hypercarbia can be due to:
  - hypoventilation
  - V/Q mismatch

*Due to differences between oxygen and $CO_2$ in their solubility and respective disassociation curves, shunt and diffusion impairments do not result in hypercarbia*

## Gas Exchange

- Hypoventilation and V/Q mismatch are the most common causes of abnormal gas exchange in the PICU
- Can correct hypoventilation by increasing minute ventilation
- Can correct V/Q mismatch by increasing amount of lung that is ventilated or by improving perfusion to those areas that are ventilated

## Mechanical Ventilation

- What we can manipulate……
  - Minute Ventilation (increase respiratory rate, tidal volume)
  - Pressure Gradient = A-a equation (increase atmospheric pressure, $FiO_2$, increase ventilation, change RQ)
  - Surface Area = volume of lungs available for ventilation (increase volume by increasing airway pressure, i.e., mean airway pressure)
  - Solubility = ?perflurocarbons?

## Mechanical Ventilation

Ventilators deliver gas to the lungs using positive pressure at a certain *rate*. The amount of gas delivered can be *limited* by time, pressure or volume. The duration can be *cycled* by time, pressure or flow.

## Nomenclature

- Airway Pressures
  - Peak Inspiratory Pressure (PIP)
  - Positive End Expiratory Pressure (PEEP)
  - Pressure above PEEP (PAP or ΔP)
  - Mean airway pressure (MAP)
  - Continuous Positive Airway Pressure (CPAP)
- Inspiratory Time or I:E ratio
- Tidal Volume: amount of gas delivered with each breath

## Modes

- Control Modes:
  - every breath is fully supported by the ventilator
  - in classic control modes, patients were *unable* to breathe except at the controlled set rate
  - in newer control modes, machines may act in assist-control, with a minimum set rate and all triggered breaths above that rate also fully supported.

## Modes

- IMV Modes: intermittent mandatory ventilation modes - breaths "above" set rate not supported
- SIMV: vent synchronizes IMV "breath" with patient's effort
- Pressure Support: vent supplies pressure support but no set rate; pressure support can be fixed or variable (volume support, volume assured support, etc)

## Modes

Whenever a breath is supported by the ventilator, regardless of the mode, the limit of the support is determined by a preset pressure *OR* volume.

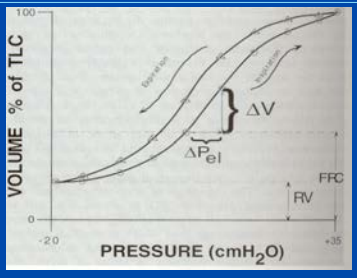
- Volume Limited: preset tidal volume
- Pressure Limited: preset PIP or PAP

## Mechanical Ventilation

If volume is set, pressure varies…..if pressure is set, volume varies…..
….according to the compliance…...

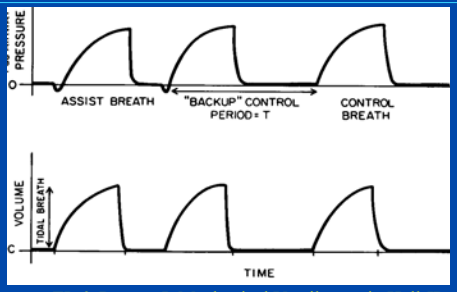
**COMPLIANCE =**
**Δ Volume / Δ Pressure**

## Compliance



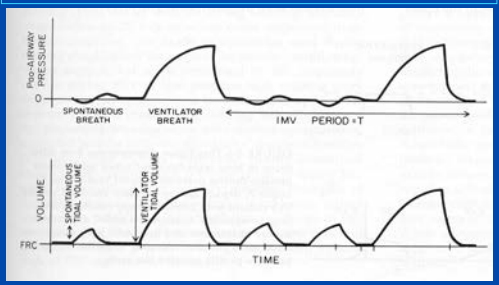

Burton SL & Hubmayr RD: Determinants of Patient-Ventilator Interactions: Bedside Waveform Analysis, in Tobin MJ (ed): *Principles & Practice of Intensive Care Monitoring*

## Assist-control, volume




Ingento EP & Drazen J: Mechanical Ventilators, in Hall JB, Scmidt GA, & Wood LDH(eds.): *Principles of Critical Care*

## IMV, volume-limited

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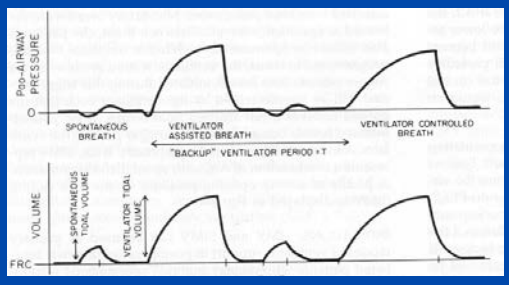
## SIMV, volume-limited

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## Control vs. SIMV

Control Modes

- **Every breath is supported regardless of "trigger"**
- **Can't wean by decreasing rate**
- **Patient may hyperventilate if agitated**
- **Patient / vent asynchrony possible and may need sedation +/- paralysis**

SIMV Modes

- **Vent tries to synchronize with pt's effort**
- **Patient takes "own" breaths in between (+/- PS)**
- **Potential increased work of breathing**
- **Can have patient / vent asynchrony**

## Pressure vs. Volume

- Pressure Limited
  - Control $FiO_2$ and MAP (oxygenation)
  - Still can influence ventilation somewhat (respiratory rate, PAP)
  - Decelerating flow pattern (lower PIP for same TV)
- Volume Limited
  - Control minute ventilation
  - Still can influence oxygenation somewhat ($FiO_2$, PEEP, I-time)
  - Square wave flow pattern

## Pressure vs. Volume

- Pressure Pitfalls
  - tidal volume by change suddenly as patient's compliance changes
  - this can lead to hypoventilation or overexpansion of the lung
  - if ETT is obstructed acutely, delivered tidal volume will decrease
- Volume Vitriol
  - no limit per se on PIP (usually vent will have upper pressure limit)
  - square wave(constant) flow pattern results in higher PIP for same tidal volume as compared to Pressure modes

## Trigger

- How does the vent know when to give a breath? - "Trigger"
  - patient effort
  - elapsed time
- The patient's effort can be "sensed" as a change in pressure or a change in flow (in the circuit)

## Need a hand??

Pressure Support

- "Triggering" vent requires certain amount of work by patient
- Can decrease work of breathing by providing flow during inspiration for patient triggered breaths
- Can be given with spontaneous breaths in IMV modes or as stand alone mode without set rate
- Flow-cycled

## Advanced Modes

- Pressure-regulated volume control (PRVC)
- Volume support
- Inverse ratio (IRV) or airway-pressure release ventilation (APRV)
- Bilevel
- High-frequency

## Advanced Modes

PRVC

A control mode, which delivers a set tidal volume with each breath at the lowest possible peak pressure. Delivers the breath with a decelerating flow pattern that is thought to be less injurious to the lung…… "the guided hand".

## Advanced Modes

Volume Support

- equivalent to smart pressure support
- set a "goal" tidal volume
- the machine watches the delivered volumes and adjusts the pressure support to meet desired "goal" within limits set by you.

## Advanced Modes

Airway Pressure Release Ventilation

- Can be thought of as giving a patient two different levels of CPAP
- Set "high" and "low" pressures with release time
- Length of time at "high" pressure generally greater than length of time at "low" pressure
- By "releasing" to lower pressure, allow lung volume to decrease to FRC

## Advanced Modes

Inverse Ratio Ventilation

- Pressure Control Mode
- I:E > 1
- Can increase MAP without increasing PIP: improve oxygenation but limit barotrauma
- Significant risk for air trapping
- Patient will need to be deeply sedated and perhaps paralyzed as well

## Advanced Modes

High Frequency Oscillatory Ventilation

- extremely high rates (Hz = 60/min)
- tidal volumes < anatomic dead space
- set & titrate Mean Airway Pressure
- amplitude equivalent to tidal volume
- mechanism of gas exchange unclear
- traditionally "rescue" therapy
- active expiration

## Advanced Modes

High Frequency Oscillatory Ventilation

- patient must be paralyzed
- cannot suction frequently as disconnecting the patient from the oscillator can result in volume loss in the lung
- likewise, patient cannot be turned frequently so decubiti can be an issue
- turn and suction patient 1-2x/day if they can tolerate it

## Advanced Modes

Non Invasive Positive Pressure Ventilation

- Deliver PS and CPAP via tight fitting mask (BiPAP: bi-level positive airway pressure)
- Can set "back up" rate
- May still need sedation

## Initial Settings

- Pressure Limited
  - $FiO_2$
  - Rate
  - I-time or I:E ratio
  - PEEP
  - PIP or PAP
- Volume Limited
  - $FiO_2$
  - Rate
  - I-time or I:E ratio
  - PEEP
  - Tidal Volume

These choices are with time - cycled ventilators. Flow cycled vents are available but not commonly used in pediatrics.

## Initial Settings

- Settings
  - Rate: start with a rate that is somewhat normal; i.e., 15 for adolescent/child, 20-30 for infant/small child
  - $FiO_2$: 100% and wean down
  - PEEP: 3-5
  - Control every breath (A/C) or some (SIMV)
  - Mode ?

## Dealer's Choice

- Pressure Limited
  - $FiO_2$
  - Rate
  - I-time
  - PEEP
  - *PIP*

  → **MAP**

  **Tidal Volume ( & MV) Varies**
- Volume Limited
  - $FiO_2$
  - Rate
  - *Tidal Volume* → **MV**
  - PEEP
  - I time

  **PIP ( & MAP) Varies**

## Adjustments

- To affect oxygenation, adjust:
  - $FiO_2$
  - PEEP
  - I time
  - PIP

  → **MAP**
- To affect ventilation, adjust:
  - Respiratory Rate → **MV**
  - Tidal Volume → **MV**

## Adjustments

- PEEP

  Can be used to help prevent alveolar collapse at end inspiration; it can also be used to recruit collapsed lung spaces or to stent open floppy airways

## *Except...*

- Is it really that simple ?
  - Increasing PEEP can increase dead space, decrease cardiac output, increase V/Q mismatch
  - Increasing the respiratory rate can lead to dynamic hyperinflation (aka auto-PEEP), resulting in worsening oxygenation and ventilation

## *Troubleshooting*

- Is it working ?
  - **Look at the patient !!**
  - **Listen to the patient !!**
  - Pulse Ox, ABG, $EtCO_2$
  - Chest X ray
  - Look at the vent (PIP; expired TV; alarms)

## *Troubleshooting*

- When in doubt, DISCONNECT THE PATIENT FROM THE VENT, and begin bag ventilation.
- Ensure you are bagging with 100% O2.
- This eliminates the vent circuit as the source of the problem.
- Bagging by hand can also help you gauge patient's compliance

## *Troubleshooting*

- Airway first: is the tube still in? (may need DL/$EtCO_2$ to confirm) Is it patent? Is it in the right position?
- Breathing next: is the chest rising? Breath sounds present and equal? Changes in exam? Atelectasis, bronchospasm, pneumothorax, pneumonia? (Consider needle thoracentesis)
- Circulation: shock? Sepsis?

## *Troubleshooting*

- Well, it isn't working…..
  - Right settings ? Right Mode ?
  - Does the vent need to do more work ?
    - Patient unable to do so
    - Underlying process worsening (or new problem?)
  - Air leaks?
  - Does the patient need to be more sedated ?
  - Does the patient need to be extubated ?
  - Vent is only human…..(is it working ?)

## *Troubleshooting*

- Patient - Ventilator Interaction
  - Vent must recognize patient's respiratory efforts (trigger)
  - Vent must be able to meet patient's demands (response)
  - Vent must not interfere with patient's efforts (synchrony)

## Troubleshooting

- Improving Ventilation and/or Oxygenation
  - can increase respiratory rate (or decrease rate if air trapping is an issue)
  - can increase tidal volume/PAP to increase tidal volume
  - can increase PEEP to help recruit collapsed areas
  - can increase pressure support and/or decrease sedation to improve patient's spontaneous effort

## Lowered Expectations

- Permissive Hypercapnia
  - accept higher PaCO2s in exchange for limiting peak airway pressures
  - can titrate pH as desired with sodium bicarbonate or other buffer
- Permissive Hypoxemia
  - accept PaO2 of 55-65; SaO2 88-90% in exchange for limiting FiO2 (<.60) and PEEP
  - can maintain oxygen content by keeping hematocrit > 30%

## Adjunctive Therapies

- Proning
  - re-expand collapsed dorsal areas of the lung
  - chest wall has more favorable compliance curve in prone position
  - heart moves away from the lungs
  - net result is usually improved oxygenation
  - care of patient (suctioning, lines, decubiti) trickier but not impossible
  - not everyone maintains their response or even responds in the first place

## Adjunctive Therapies

- Inhaled Nitric Oxide
  - vasodilator with very short half life that can be delivered via ETT
  - vasodilate blood vessels that supply ventilated alveoli and thus improve V/Q
  - no systemic effects due to rapid inactivation by binding to hemoglobin
  - improves oxygenation but does not improve outcome

## Complications

- Ventilator Induced Lung Injury
  - Oxygen toxicity
  - Barotrauma / Volutrauma
    - Peak Pressure
    - Plateau Pressure
    - Shear Injury (tidal volume)
    - PEEP

## Complications

- Cardiovascular Complications
  - Impaired venous return to RH
  - Bowing of the Interventricular Septum
  - Decreased left sided afterload (good)
  - Altered right sided afterload
- Sum Effect…..decreased cardiac output (usually, not always and often we don't even notice)

## Complications

- Other Complications
  - Ventilator Associated Pneumonia
  - Sinusitis
  - Sedation
  - Risks from associated devices (CVLs, A-lines)
  - Unplanned Extubation

## Extubation

- Weaning
  - Is the cause of respiratory failure gone or getting better ?
  - Is the patient well oxygenated and ventilated ?
  - Can the heart tolerate the increased work of breathing ?

## Extubation

- Weaning (cont.)
  - decrease the PEEP (4-5)
  - decrease the rate
  - decrease the PIP (as needed)
- What you want to do is decrease what the vent does and see if the patient can make up the difference….

## Extubation

- Extubation
  - Control of airway reflexes
  - Patent upper airway (air leak around tube?)
  - Minimal oxygen requirement
  - Minimal rate
  - Minimize pressure support (0-10)
  - "Awake" patient