Mechanical Ventilation in the Pediatric Emergency Room & Intensive Care Unit

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Disclosures

- I have no disclosures to report

Objectives

- History of mechanical ventilation in children
- A brief overview of types of ventilation available
- Indications and challenges of the non-invasive ventilation modes
- Indications and challenges of the advanced invasive ventilation modes

History of mechanical ventilation

- First written idea of assisted ventilation: Galen of Pergamon(~175 AD)
  - Use of bellows to inflate the lungs of deceased animals
  - Discovered the larynx produced your voice
- First idea of external negative pressure ventilation: John Mayow (1638)
- First negative pressure ventilator: John Dalziel (1832)
  - First “tank respirator”: Patient sitting in an air tight box with head sticking out with manual bellows

History of mechanical ventilation

- The first widely used negative pressure ventilator: The Drinker Respirator (aka Emerson Iron Lung)
  - Designed by Philip Drinker and Louis Agassiz Shaw Jr. (1928)
  - Powered by an electric motor and 2 air pumps from a vacuum cleaner
  - First ever use: 8 yr old girl w/ Poliomyelitis at Boston Children's Hospital 1928

History of mechanical ventilation

- Emerson Iron Lung

Hilpertshauser, Mary. *Iron Lung CDC*. Digital image. Wikipedia, 2004. Web. 01 Apr. 2014.

History of mechanical ventilation

- Boston Children's Hospital 4 patient chamber ventilator

History of mechanical ventilation

- Movement away from negative pressure devices (1960s)
  - Large, taking up much space, difficult to access patient
  - No PEEP
  - Significant leakage leading to patient cooling
  - "Tank shock" – blood pooling in abdomen and lower extremities
- Intermittent positive pressure breathing (IPPB) (1950s)
  - Brief boost of positive airway pressure in patients with chronic respiratory failure or to deliver aerosolized bronchodilator to COPD patients
  - Studies failed to demonstrate benefit over aerosol treatment alone via nebulizer

History of mechanical ventilation

- Invasive Positive Pressure machines
  - First generation 1940s to 50s
    - Only volume controlled
    - No patient triggered ventilations
    - No PEEP
    - No monitors
  - Second generation
    - Simple monitors – TV and RR
    - Patient triggered ventilations
    - IMV, SIMV introduced (only volume control)
- Third generation
  - Ex Servo 300, Bear 1000
  - Addition of microprocessor
  - Markedly more responsive to patient demand
  - SIMV w/ Pressure control, APRV
  - More bells and whistles (literally)
- Fourth generation
  - Current generation

Types of mechanical ventilation

- Non-invasive mechanical ventilation
  - Negative Pressure Ventilation (NPV)
  - Noninvasive Positive Pressure Ventilation (NIPPV)
    - CPAP, BiPAP, HHNC
- Conventional Invasive mechanical ventilation
  - CMV, AC, VC, IMV, SIMV
- Advanced ventilation
  - HFOV
  - APRV
  - ECMO (V-V and V-A)

Challenges to ventilation in children

- Smaller airway
- Multiple sized tubes and blades based on weight/size
- Mask sizes available at hand that are too big or too small
- Appropriate tubing for pediatric patients
- Fear of the machine, the staff, or the surroundings
- Sensory issues
- Hunger
- Sedation, Sedation, Sedation!

Noninvasive ventilation

- Positive effects
  - Decreases work of breathing
  - Increases functional residual capacity
  - Stabilizes chest wall to reduce retractions
  - Recruits alveoli with PEEP
  - Increases tidal volume and minute ventilation
  - Maintains upper airway patency
- Benefits over endotracheal intubation
  - Decrease upper airway trauma
  - No vocal cord dysfunction
  - Less sedation needed
  - No need for paralytics
  - Less risk of aspiration
  - Patients can still communicate
  - If successful, fewer oxygen days leading to less oxygen toxic side effects (ROP)

Types of noninvasive ventilation techniques

- CPAP – Continuous positive pressure ventilation
  - Constant pressure during inspiration and expiration
  - 5-10 cm H_2O
  - Delivered by binasal prongs, oronasal masks, nose masks, or nasopharyngeal prongs
  - Nasal CPAP – used to great effect in the Neonatal ICU
- BiPAP – Bi-level positive airway pressure
  - Provides 2 levels of positive airway pressure during respiratory cycle
  - Higher pressure IPAP during inspiration (10-16 cm H_2O)
  - Lower pressure EPAP during expiration (5-10 cm H_2O)
  - Set rate or back-up rate
  - Can be patient triggered

Types of noninvasive ventilation techniques

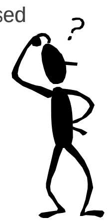
- Humidified high-flow nasal cannula (HHFNC)
  - Delivers warm, humidified air
  - Up to 8 L/min in infants and 40 L/min for older children
  - Less nasal irritation
  - Comparable to nasal CPAP
- Nasal intermittent positive pressure ventilation (NIPPV)
  - Provides periodic increases in positive pressure above a baseline fixed pressure
  - Has 2 flow meters compared to nasal CPAP's 1 in order to add additional flow
  - Additional flow delivered at set rate, not patient triggered

Contraindications to NIV

- Impaired mental status
- Poor cooperation
- Agitation
- Inability to protect the airway
- Recent upper GI surgery
- Hemodynamic instability/shock
- Inappropriate mask size/type available

Noninvasive ventilation

- How do you know if it's working?
  - Assess within 1-2 hours
  - Note if patient is tolerating it to start
  - Decreased respiratory rate, retractions, or work of breathing
  - Airway occlusive events decreased
  - Improved lung volumes noted
  - O_2 saturation improved



- How do you know if it's failed?
  - Persistent or progressive respiratory distress and/or tachypnea
  - Tired appearance/worsening mental status
  - Increased agitation/anxiety
  - Vomiting, excessive secretions
  - Hemodynamic instability
  - Persistent hypoxia

Noninvasive ventilation – when to use it?

- Chronic patients
  - Nocturnal hypoventilation
    - Chronic respiratory failure patients with restrictive chest wall deformities and neuromuscular disease
      - Can delay need for tracheostomy and be effective in acute exacerbations
    - Cystic fibrosis patients
      - Can bridge to lung transplants in end stage lung disease

Noninvasive ventilation – when to use it?

- Acute patients
  - Pneumonia
    - Maybe? Little concrete evidence to support improved outcomes
    - Fortenberry et al described improvement of 25 out of 28 patients on BiPAP with concurrent pneumonia and neurologic disorders - avoided intubation
  - Asthma
    - Possibly? Specifically status asthmaticus
    - Teague et al showed 19 of 26 patients improved on BiPAP – decreased RR and work of breathing
    - Joshi et al showed improvement in RR, PCO_2, and oxygen requirement for 18 of 29 patients for primary parenchymal disease but no improvement in O_2 saturation
  - Bronchiolitis
    - Some evidence shows improvement in number of O2 days and reduced number of ventilator associated infections (Dels, Estrada & Abramo, 2009)
  - Acute Chest
    - Some evidence to support initiation of BiPAP on patients with acute chest to significantly reduce HR, RR, and O_2 requirement (Dels, Estrada & Abramo, 2009)

Noninvasive ventilation – strategies for children

- Start easy, work your way up
- Appropriate mask size and fit
- Child life, music therapy
- Recruit the parents!
- Pharmacotherapy: sedation without airway compromise
  - Ketamine
  - Dexmedetomidine

Types of invasive mechanical ventilation

- Conventional Ventilation:
  - CMV, IMV, SIMV, AC, etc
- Advanced ventilation
  - APRV – Airway pressure release ventilation
  - HFOV – High frequency oscillator ventilation
  - ECMO – Extracorporeal membrane oxygenation

The problems with conventional ventilation

- Barotrauma – Alveolar and small airway damage due to high inspiratory pressures
- Volutrauma – alveolar over-distension as a result of excessive volume
- Atelectrauma – damage caused by sheering forces due to cyclic repetition of collapse and reopening of dependent alveoli
  - Can be secondary to both direct mechanical factors and to cell damage from inflammatory mediator based
  - Sometimes this zone where the alveoli do not collapse versus being over distended in the diseased lung is too small for conventional ventilation to maintain tidal volumes

High frequency ventilation

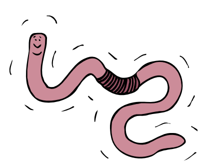
- High frequency jet ventilation (HFJV) introduced in 1967 by Sanders to facilitate gas exchange during bronchoscopies
- High frequency positive pressure ventilation (HFPPV) introduced in 1970s by Oberg and Sjostrand
- Both HFJV and HFPPV depended on passive recoil of chest to eliminate CO_2
- High frequency oscillator ventilation (HFOV) developed in late 1970s/early 1980s
  - Able to keep lung volumes stable and controllable compared to the previous iterations
  - Active exhalation

HFOV

- Pressure oscillates around a constant distending pressure
- Tidal volumes generated are small
  - 0.1-5 ml/kg
  - Smaller than dead-space volume
- Breathing frequency > 1 Hz or 60 breaths per minute (usually 3-15 Hz)
- Ventilation is a function of amplitude, inspiratory time, and frequency
  - As frequency decreases, the delivered tidal volume increases and ventilation increases
- Oxygenation is a function of FiO_2 and the mean airway pressure (Pmaw)
- Gas transport is achieved through combination of convection and diffusion flow
  - More convection towards the proximal alveoli
  - More diffusion near the distal alveoli

HFOV

- Amplitude is the delta pressure to which the oscillator goes above and below the mean airway pressure
  - Initially set to achieve adequate chest wall vibration (aka the 'wiggle')
  - Wiggle is different for different sized patients
    - Neonates: up to chest wall
    - Pediatrics: shoulders to belly button
    - Adults: shoulders to mid thigh



HFOV

- When to use it?
  - Mostly used in neonates, although has been used in older pediatrics since mid 90s
  - Now used in some ARDS cases in adults as well.
  - Still seen as a rescue therapy in children with diffuse alveolar disease (DAD) such as ARDS, pneumonia, lung contusions
    - Seen with increased airway resistance and hyperinflation
- Criteria to start includes:
    - Ventilatory failure with plateau pressure > 30 cm H_2O despite use of permissive hypercapnia for at least 2 hours in conventional ventilation
    - Or an oxygenation index > 13 demonstrated by 2 blood gas measurements over a 6 hour period (or FiO2 > 0.6, PEEP > 10) in conventional ventilation
    - Earlier initiation associated with better outcomes

HFOV

- Things to watch for:
  - Watch for de-recruitment:
    - Every time patient is disconnected from circuit, de-recruitment occurs!
    - Use inline suction as opposed to open suction
  - Hyperinflation: follow with CXR
  - Wiggle:
    - If wiggle diminishes or becomes asymmetric, beware!
    - Could be obstructed or slipped ET tube or pneumothorax
  - Hemodynamic instability:
    - Stroke volume will increase with increased amplitude, decreased frequency, or increase in inspiratory time (increased Pmaw)
    - Hypotension can occur and may need fluid boluses to increase central venous pressure
  - Monitor blood gases to monitor $PaCO_2$ and pH

HFOV

- Sedation
  - Usually heavy sedation needed to avoid patient from moving and "fighting" the vent
    - Spontaneous breathing causes unstable Pmaw
  - Paralytics may be required
- HFOV failure criteria:
  - Inability to decrease FiO2 within first 24 hours
  - Inability to improve or maintain ventilation

APRV – Airway pressure release ventilation

- Time triggered, pressure limited, and time cycled mode of ventilation
- First described in 1987 by John Downs
- Consists of a high flow continuous positive pressure around which a patient can breath spontaneously
- Regular intermittent rapid exhalations allowing outflow of gas from the lungs (tidal ventilation) without full collapse of alveoli
- Can also be used in a completely apneic patient

APRV

- Mean airway pressure drives oxygenation (Pmaw) which is determined by the high and low pressure settings (P High, P Low)
  - While Pmaw is usually higher than in conventional ventilation, PIP is much lower
- Ventilator rate: function of the set time the patient remains in the high and low pressures (T High, T Low)
  - Longer inspiratory times than expiratory times
    - Inverse ratio ventilation
    - The longer T High, the more recruitment occurs from sustained plateau pressures, and the higher the release volume becomes
    - T low set long enough to achieve ventilation but short enough not to collapse alveoli
- Unrestricted, spontaneous breathing throughout entire cycle

APRV

- When to use it?
  - Specifically for use in a patient with a sustained spontaneous respiratory effort that has failed conventional ventilation from acute lung injury
  - Poor compliance lungs with diminished functional residual capacity from collapsed alveoli

APRV

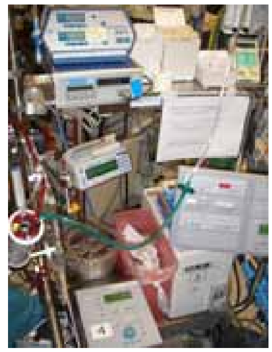
- Advantages
  - Lower Paw for given tidal volume and thus lower barotrauma
  - Lower atelectrauma
  - Lower minute ventilation
  - Lower need for sedation (in older children)
  - No need for neuromuscular blockade (in older children)
  - More patient comfort with being able to take spontaneous breaths anytime
  - Limited to no effect on cardio-circulatory function, unlike HFOV\
  - Decrease in VQ mismatch

APRV

- Disadvantages:
  - Volumes affected by changes in lung compliance and resistance
  - Superiority to conventional modes has not been demonstrated in children
    - Evidence suggests no harm or no better than conventional modes with mortality in pediatric patients (Frawley & Habashi, 2001)
    - Only used when conventional ventilation has failed to improve oxygenation

ECMO – Extra corporeal membrane oxygenation

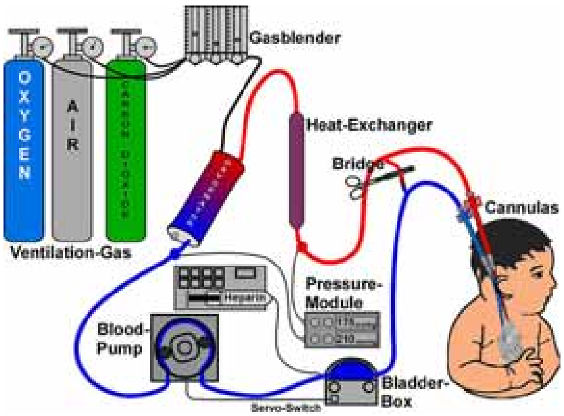
- Provides mechanical cardiorespiratory support in the setting of severe pulmonary and hemodynamic failure refractory to medical management
- Blood is removed from venous circulation, oxygenated, and returned to the body either through the venous or arterial circulation



ECMO

- Two types
  - Venous-Venous ECMO
    - Oxygenated blood is returned to venous circulation where it subsequently delivered to pulmonary bed
    - Appropriate for pulmonary failure only
  - Venous-Arterial ECMO
    - Blood removed from internal jugular vein, oxygenated and returned to aortic arch via right common carotid artery
    - Permits both cardio and respiratory support

ECMO



ECMO

- Indications:
  - Respiratory:
    - Bacterial, viral, aspiration pneumonia, ARDS
    - Congenital diaphragmatic hernia
    - Refractory hypoxemia with Oxygenation Index > 40 and PaO_2/FiO_2 < 100 despite maximal medical and respiratory support
  - Cardiac:
    - Congenital heart conditions
    - End stage cardiac disease as a bridge to transplant
- Contraindications:
  - Irreversible renal, hepatic, or respiratory failure
  - Irreversible cognitive compromise
  - Gestational age < 34 weeks, Birth weight < 2000 g
  - Mechanical ventilation > 10 days
  - Chronic lung disease or any malignancy
  - Contraindication to anticoagulation

ECMO

- Outcomes
  - Respiratory:
    - A UK study showed 64% survive to decannulation and 56% survived to discharge
    - With longer standing programs, survival to discharge increases
    - The longer the need for ECMO the lower the survival rate, although much longer times are tolerated than in the cardiac group
- Limitations
  - Located only in tertiary level intensive care units
  - Need a cardiothoracic or trauma surgeon in house for cannulation of patient
  - Highly specialized staffing required (ECMO specialists, ECMO trained intensivists, nurses, and other pediatric subspecialists)
  - Will need anticoagulation and dialysis
  - Will still need to be intubated and ventilated
  - Will need sedation and neuromuscular blockade

ECMO

- Complications:
  - Hemorrhage
    - During cannulation
    - Pulmonary hemorrhage
    - Intracranial hemorrhage
    - GI bleeding
  - Thromboembolism
  - Infections
  - Swelling
  - Renal/Hepatic dysfunction

ECMO – ventilation considerations

- ECMO still requires mechanical ventilation
- VV-ECMO
  - Ventilator associated lung injury (volutrauma, barotruama, atelectrauma, inflammation)
    - Low volumes may still cause injury in lungs with minimally aerated alveoli
  - Volume and pressure limited strategies beyond those for conventional ARDS treatment may be required
  - Trick is to minimize atelectrauma, alveolar strain, and over distension
    - Low tidal volumes (<4 ml/kg in older children) coupled with higher PEEP (>10 mm H_2O)
    - Decrease the opening and closing of alveoli caused by higher tidal volumes and rates (lower RR)
  - Try to minimize oxygen toxicity to areas that are over ventilated and under perfused
    - Cause of reabsorption atelectasis – derecruitment in the setting of pure oxygen (decrease FiO_2)

ECMO – ventilator strategies

- VA-ECMO
  - Pulmonary arterial flow reduced with increased pressures
  - VQ mismatch – overventilation
  - Right and left ventricular flow affected with both VV and VA ECMO
  - Increased PEEP can cause increased pulmonary vascular resistance, decrease preload and decrease cardiac output

Questions?

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