Optimal Ventilation of the Pediatric Patient in the OR

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Disclosures

Consulting
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Topics for Discussion

- Historical Perspective
- Technology Advances
- Ventilation Modes
- Monitoring to Optimize Ventilation

The Pediatric Challenge

- Small errors in the intervention can be significant with the potential for injury or inadequate effect
  - Ex: Fluid & Drug Administration
- Mechanical Ventilation
  - Small volume variations can be a significant percentage of intended volume
    » Hypo/Hyper ventilation
    » Volu/Barotrauma

Tidal Volume = 10-12 mls/kg

- 18 laparotomy patients, 24-87 yo
- Pressure Ventilation 15-20 cmH2O
- Decrease CO2 and Ewave pressures during mechanical ventilation
- Studied recruitment maneuvers

Traditional Anesthesia Machine

Set Volume and Delivered Volume are not Identical
Why Pressure Controlled Ventilation?

- Volume Controlled Ventilation inaccurate
  - Circuit Compliance
  - Fresh gas flow
  - Leaks
- Pressure Controlled Ventilation Worked
  - Tidal volume depends upon insp pressure and lung compliance
  - Independent of circuit compliance and fresh gas flow
  - Maximum volume capacity to achieve desired pressure

Modern Anesthesia Ventilator

- Technology Differences
  - Bellows
  - Piston
  - Volume Reflector
  - Blower
- GOAL: Accurate volume delivery to the airway independent of circuit compliance and fresh gas flow

Compliance & FGF Compensation
Safety & Compliance Compensation

- Limits of compensation
  - Compliance compensation adds volume to insure set volume delivered to airway
  - Changing circuit compliance after compliance test
    - Decreased circuit compliance – risk of hyperinflation
    - Increased circuit compliance – risk of hypoinflation
  - Most ventilators limit compensation volume
  - e.g., add humidifier, expand circuit

**PERFORM LEAK AND COMPLIANCE TEST WITH THE CIRCUIT CONFIGURATION YOU INTEND TO USE**

Dead Space & Mechanical Ventilation

- Definition:
  - Bidirectional flow but no gas exchange
  - Circle system: Patient side of the Y-piece
  - Wasted ventilatory effort
- Pediatric patients especially susceptible to increased dead space
  - Small changes in dead space can cause big changes in $V_D/V_t$
  - Apparatus dead space can be significant

Typical Apparatus Dead Space

**Do I need an ICU Ventilator?**

- Better Volume Delivery? No
- Better Pressure Delivery? No
- Advanced Modes of Ventilation? No
  - Supported vs Controlled
- Use of Nitric Oxide? No
- HFOV? Yes
- Disadvantages of the ICU ventilator
  - No anesthetic vapor
  - Transition to manual ventilation

**Typical Apparatus Dead Space**

What is the best Ventilation Mode?

- Volume?
- Pressure?
- Pressure Support?
- Other?

Small Volume Ventilation

The New England Journal of Medicine

NEJM 2000;342;1301.

LPV and the Anesthetized Patient

NEJM 2013;369;428.

LPV & Anesthetized Patient

- Randomized Prospective Study
  - Traditional (10-12 mls/kg no PEEP, Recr) v LPV (6-8 mls/Kg + PEEP/Recr)
  - 55 v 21 patients had one or more major pulm or extrapulmonary Cx within 7 days
  - Complications: Pneumonia, resp failure, sepsis
  - LOS 13 v 11 days

Implications for Children

- Lung protective ventilation beneficial in adults
  - Volume 6-8 mls/kg
  - Pressure Limit < 30 cmH2O
  - PEEP
  - Recruitment maneuver
- Most meaningful in “at risk” patients
- Accurate small volume delivery
  - Relies upon compliance compensation
  - Minimum volumes to 20 mls (3 kgs)

Making Sense of the Terms

- Controlled Modes
  - VCV: Volume Controlled Ventilation
  - PCV: Pressure Controlled Ventilation
  - Autoflow, PRVT, PCV-VG:
    - Pressure Controlled Ventilation Volume Guarantee
- Supported Modes
  - Pressure Support Ventilation
- Hybrid Modes
  - VCV/PS: Synchronized Volume Controlled Ventilation with Pressure Support
  - PCV/PS: Synchronized Pressure Controlled Ventilation with Pressure Support
**Volume Controlled Ventilation**

- **VOLUME CONSTANT**
  - Flow = Set Volume ÷ Set i-Time
- PRESSURE VARYs with lung compliance
  - Peak Pressure at end inspiration
- Ventilator does not know anything about lung compliance

**Pressure Controlled Ventilation**

- **VOLUME VARYs with lung compliance**
  - Peak flow set, flow changes with lung compliance
- PRESSURE CONSTANT
  - = Set Pressure ÷ Set i-Time
- Ventilator does not know anything about lung compliance

**PCV and VCV Indications**

- **VCV**
  - Preset tidal volume is desired
  - Leaks are unlikely
  - Control of pressure is not a priority
  - Pressure limit can protect against transient compliance changes e.g., cough, surgical maneuver
  - If you hit the pressure limit the set volume is not delivered!
- **PCV**
  - Control of pressure is desired?
    - Small patients < 3 kgs
    - Leaks e.g., uncuffed ETT, bronchopleural fistula
    - Underlying lung pathology i.e., heterogeneous compliance (ARDS)

**PCV-VG or AUTOFLOW**

- **VOLUME CONSTANT**
  - Peak flow set, flow changes with lung compliance
- PRESSURE CONSTANT
  - = Set Pressure ÷ Set i-Time
- Ventilator must learn lung compliance
- Measures relationship between volume and pressure
- Limited if frequent changes in lung compliance

**Selecting the Ventilation Mode**

- Volume is important
  - Lung protective ventilation
  - Small tidal volumes must be reliable
  - PEEP is important
- Excessive pressure should be avoided
  - Pressure limit protective but not a strategy
- Square wave pressure can improve gas exchange in difficult to ventilate patients
- New anesthesia ventilators facilitate this approach to ventilation
  - Accurate volume delivery
  - PRVT, Autoflow, PCV-VG

**Pressure Support**

- Flow and volume depend upon
  - Lung compliance
  - Patient Effort
- Physiologic Benefits
  - Reduced work of breathing
  - Improved Venous Return
  - Reduced atelectasis
Role of Pressure Support
- Facilitate use of spontaneous ventilation
  - Reduce work of breathing
  - Offset respiratory depressant effects
- Improved gas exchange
- Improve hemodynamics
- Titrate anesthetics e.g. narcotics
- Assess depth of anesthesia
- Emergence
  - Transition to spontaneous ventilation
  - Eliminate anesthetic agents

Respiratory Monitoring
- Patient safety
  - Circuit Problems - Disconnections, Leaks, incompetent valves, absorber problems
  - Airway integrity - Extubation, obstruction, endobronchial intubation
- Document ventilator performance
  - Is the ventilator performing as set?
- Guide clinician to the optimal ventilation strategy

Bedside Respiratory Monitoring
- Gas Exchange
  - Gold standard: Arterial Blood Gas Analysis
  - Inspired (and expired) oxygen concentration
  - Capnography: Time and volume based
  - Pulse oximetry
- Pulmonary Mechanics
  - Airway pressure
  - Exhaled tidal volume
  - Spirometry: P/V and F/V loops

Goals of Optimizing Ventilation
- Oxygenation
  - Maximum PaO2
  - Minimum FiO2
- CO2 Elimination
  - Acceptable PaCO2
- Lung Compliance
  - Maximum volume
  - Minimum pressure
- Are bedside monitors helpful to meet these goals?

Pulse Oximetry
- Convenient
- Measures saturation not partial pressure
- Cannot detect moderate oxygenation changes when using supplemental oxygen
- Useful to assess oxygenation changes at low FiO2

Pulse Oximetry
- Saturation v inspired oxygen curves

Ref: Janssen KG, ECMC 16:337, 2000
Capnography
- Convenient
- Well established
- Good monitor of airway integrity
- Limited utility for effectiveness of ventilation
  - Unpredictable arterial to end-tidal CO2 gradient
  - Small tidal volumes (decreased Vd/Vt) will influence the gradient
- Arterial blood gas analysis is required when control of carbon dioxide is essential

Lung Compliance
- Compliance ~ Volume/Pressure (mls/cmH2O)
- What Pressure to monitor?
  - Peak pressure
  - Plateau Pressure
  - Mean pressure
  - PEEP
- Pressure is generated by
  - Flow through a resistance
  - Volume filling a compliance
  - PEEP
- Volume Monitoring
  - Exhaled valve sensor
  - On Airway measurement

Compliance Assessment
- Dynamic Compliance
  - Determined by resistance and compliance
  - Influenced by external factors
    - Resistance: ETT, obstruction
    - Flow: Ventilator settings/exp volume mode
  - Dynamic Compliance
    - Can be estimated in absence of flow
    - Cdyn = Peak Pressure / Exhaled volume
- Static Compliance
  - Can be estimated in absence of flow
  - Cstatic = Plateau pressure / Exhaled volume

Continuous Spirometry
- Pressure/volume and Flow/volume Loops
- Breath to breath lung compliance
- No information on gas exchange
- New ventilator technology facilitates measurement
- Influenced by Ventilator mode

PV Loops and Ventilator Mode
- VCV v PCV
Optimal Ventilation Strategy

- Oxygen
  - Avoid 100% O2 without PEEP during induction and emergence
    - Consider ARM + PEEP when using 100% oxygen
- Small tidal volume (6-8 ml/kg) with PEEP is preferable
  - Proper use of compliance compensation essential
- Liberal use of PEEP during controlled ventilation
- Minimize dead space
- Volume Targeted Mode like Autoflow is desirable
- Consider spontaneous ventilation if pressure support is available

Optimal Ventilation Strategy (cont)

- Monitor to optimize ventilation
  - Pulse oximetry: Keep the FiO2 < 30%
    - Desaturation indicates oxygenation problem
  - Capnography: Acceptable ETCO2
  - Lung compliance: Maximum volume at minimum pressure
- If oxyhemoglobin saturation decreases
  - Do NOT just increase FiO2
  - Can ventilation be improved?
    - Alveolar Recruitment Maneuver and PEEP
    - Ventilation Mode: Square Pressure wave, increased i-Time
    - Supported spontaneous ventilation