ADVANCED CAPNOGRAPHY

Objectives
- List three indications for capnography.
- Differentiate between mainstream and sidestream capnography.
- Given a time-based capnogram, identify and distinguish between the phases.
- Given a time-based capnogram, interpret any abnormality present.
- Given a volume-based capnogram, identify and distinguish between the phases.
- Given a volume-based capnogram, state the significance of each phase.

Objectives
- Given a volume-based capnogram, interpret any abnormality present.
- List two instances where volume-based capnography can lead to improved patient management.
- State the formula used for the calculation of non-invasive cardiac output via the CO₂ Partial-Rebreathing method.
- Describe the set-up used to measure cardiac output via the CO₂ Partial-Rebreathing method.
- List two additional uses for capnography.

Physiology of Carbon Dioxide
ALL THREE ARE IMPORTANT!

Carbon Dioxide Monitoring Technology
- Mass Spectroscopy
- Methods of Sampling
  - Mainstream
  - Sidestream
  - Microstream
Key Technological Issues

• Calibration
• Moisture Control
• Sample flow rate
• Transit time
• Response time

Sidestream vs. Mainstream

Phases of the Time Capnogram

• Phase I: Inspiration
  - No CO₂ detected (hopefully)
• Phase II: Appearance of CO₂ in the system.
  - Mixed alveolar and deadspace gas.
• Phase III: Plateau
  - Constant emptying of alveolar gas.
  - Presence of CO₂ through the end of the breath.
• Phase IV: Washout of CO₂ from subsequent inspiration.

Abnormal Waveforms

Sudden loss of PETCO₂ to zero or near zero indicates immediate danger because no respiration is detected.
• Esophageal intubation
• Complete airway disconnect from ventilator
• Complete ventilator malfunction
• Totally obstructed/kinked endotracheal tube

Abnormal Waveforms

Exponential decrease in PETCO₂ reflects a catastrophic event in the patient’s cardiopulmonary system.
• Sudden Hypotension/massive blood loss
• Circulatory arrest with continued ventilation
• Pulmonary embolism
• Cardiopulmonary Bypass
**Abnormal Waveforms**

Gradual decrease in PETCO₂ indicates a decreasing CO₂ production, or decreasing systemic or pulmonary perfusion.
- Hypothermia
- Sedation
- Hyperventilation
- Hypovolemia
- Decreasing Cardiac Output

**Artifacts with Time-Based Capnograms**

- Patient efforts
  - “Curare cleft”
- Cardiac Oscillations

**End-Tidal CO₂**

**Clinical Uses of Capnography**

- Weaning
- Hyperventilation monitoring
- Use in Cardiac Arrest
  - Intubation verification
  - Restoration of Spontaneous Circulation
- Easy Cap

**Volumetric Capnography**

**The Normal Volume-Based Capnogram**
Checklist for Interpreting a Volume-Based Capnogram

- **Phase I – Deadspace Gas**
  - Rebreathing? (1)
  - Deadspace seem right?
- **Phase II – Transitional Phase**
  - Transition from upper to lower airways.
  - Should be steep. (3)
  - Represents changes in perfusion.
- **Phase III – Alveolar Gas Exchange**
  - Changes in gas distribution.
  - Increased slope = mal-distribution of gas delivery. (5)
  - End of Phase III is the PETCO₂ (6)
  - Area under the curve represents the volume of expired CO₂ (VCO₂).
  - Exhaled volume (8)

The Normal Volume-Based Capnogram

Waveform Phases

- **Phase 1**
  - ↑ depicts an ↑ in airways dead space.
- **Phase 2**
  - ↓ slope depicts reducing perfusion.
- **Phase 3**
  - ↑ slope depicts mal-distribution of gas.

Clinical significance

- ↑ phase 1
  - Phase 1 – relatively short
  - Phase 1 - prolonged
Phase 2 assessment

- If ↓ in phase 2
  - Assure stable minute ventilation
  - Assess PEEP level
  - ↑ intrathoracic pressure may cause ↓ venous return
  - Assess hemodynamic status
  - Is minute ventilation stable?
  - Volume resuscitation or vasopressors may be indicated

↓ Phase 2

- When minute ventilation is stable, indicative of a ↓ in perfusion.

Phase 3 assessment

- If ↑ or absent phase 3 mal-distribution of gas at alveolar level exists
  - Assess for appropriate PEEP level
  - Inadequate PEEP may be present
  - Bronchospasm
    - Bronchodilator tx my be indicated
  - Structure damage at alveolar level may be present
    - Pneumothorax?

↑ Phase 3

- Slope of phase 3 present and level
- Phase 3 absent
**Effective Tidal Volume**

- The volume of gas between the end of Phase I and the end of Phase III.
- Phase I represents the volume of gas being delivered from the ventilator which doesn’t participate in gas exchange.
  - Monitoring of the effective tidal volume (and $\overline{\text{CO}_2}$) can indicate on a breath-by-breath basis when PaCO₂ changes will be occurring before they actually rise.

**Area X = Vol CO₂**

Allows determination of VCO₂ in one min. (200 mL/min.)

**$\dot{V}_\text{CO}_2$**

- $\dot{V}_\text{CO}_2$ represents the volume of CO₂ eliminated.
  - This is usually the same as what is produced.
  - CO₂ balance is dependent on four factors:
    - Production
    - Transportation (cell to blood & blood to lungs)
    - Storage (conversion to CO₂ containing substances in the muscle, fat and bone)
    - Elimination
  - Monitoring $\overline{V}_\text{a}$ and $\dot{V}_\text{CO}_2$ allows for evaluation of a successful weaning process.

**Waveform Regions**

- Z = anatomic $V_D$; Y = $V_D$ Alveolar
- $\% \text{CO}_2$ in Arterial Blood

**Sum of $V_{\text{Danat}}$ (Z) and $V_{\text{Dalv}}$ (Y) is Physiologic $V_D$**

- Phys $V_D / V_I$:
  \[ \frac{\text{PaCO}_2 - \text{P}_{\text{eCO}_2}}{\text{PaCO}_2} = \frac{Y + Z}{X + Y + Z} \]

- Alveolar Ventilation
- Min. Vol. CO₂ (VCO₂)
Uses of Volumetric Capnography

- Assess work of breathing during weaning trial.

Using V\textsubscript{t}alv and VCO\textsubscript{2} to Recruit Alveoli in a Postoperative CABG Patient Suffering from Hypoxemia

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Using V\textsubscript{t}alv and VCO\textsubscript{2} to Recruit Alveoli

- Patient Profile
  - 72 yo male, post-op CABG, MV
- Clinical Challenge
  - Developed a low Sp\textsubscript{O2} within 2 hours of arrival into the ICU
  - F\textsubscript{IO2} and PEEP increased, no acceptable change in Pa\textsubscript{O2} and Sp\textsubscript{O2}
- Clinical Intervention
  - Lung recruitment

Using V\textsubscript{t}alv and VCO\textsubscript{2} to Recruit Alveoli

- Clinical Course
  - PEEP increased by 2 cm H\textsubscript{2}O every 10 minutes
  - Observed V\textsubscript{t}alv, VCO\textsubscript{2} and Sp\textsubscript{O2}
- Monitoring Data
  - Red arrows show PEEP increases
  - No deterioration in VCO\textsubscript{2}, V/Q stable
  - V\textsubscript{t}alv starts to increase at 16 cm H\textsubscript{2}O, alveoli are being recruited
  - Sp\textsubscript{O2} responded at 20 cm H\textsubscript{2}O

Using V\textsubscript{t}alv and VCO\textsubscript{2} to Recruit Alveoli

- Summary
  - V\textsubscript{t}alv is an ideal parameter to show alveolar recruitment
  - VCO\textsubscript{2} indicates V/Q status during the procedure
  - Sp\textsubscript{O2} did not show improvement until best PEEP
  - V\textsubscript{t}alv combined with VCO\textsubscript{2} were best to indicate increased PEEP levels were working
Uses of Volumetric Capnography

- **Optimal PEEP**
  - Overdistension leads to increased $V_{danat}$ and reduced perfusion.
  - Increased $V_{danat}$ can be assessed by an increase in Phase I volume.
  - Reduced perfusion can be assessed by a decrease in Phase II slope combined with a decrease in VCO$_2$.

**Increasing PEEP -**

- Expanded Airways increase $V_{danat}$ (zone Y)
- Expanded alveoli restrict perfusion so increased $V_{dalv}$ (Zone Z)

**VCO$_2$ to Determine Optimal PEEP**

- **Patient Profile**
  - 25 yo male, motorcycle accident
  - Head injury, rib fractures
  - Pentobarbital induced coma
- **Clinical Challenge**
  - Developed acute lung injury
  - Low PaO$_2$, SpO$_2$

**Clinical Intervention**

- Maximize lung recruitment
- Determine optimal PEEP
  - Without adversely affecting intracranial pressures
- **Clinical Course**
  - Monitor VCO$_2$ and VA
  - Increase PEEP in 2 cm H$_2$O increments

**Results**

- PEEP increased from 14 to 20
- Each step increased VA, VCO$_2$ initially decreased but recovered
- At PEEP of 22, VA did not increase, VCO$_2$ did not recover
- PEEP reduced to 20, VCO$_2$ recovered
**VCO₂ to Determine Optimal PEEP**

- **Determining Optimal PEEP**
  - **VA**
    - Showed sharp rises after initial PEEP settings
    - A result of alveolar recruitment
  - **VCO₂**
    - Initial decrease after PEEP increase, recovered quickly
    - Confirmed that pulmonary perfusion was not compromised

**Improvement in Distribution of Ventilation in Asthma**

- **Asthma — Day 1 (dark) Day 5 (blue)**

**Which graph represents ARDS?**

- Graphs show PEco₂ vs. Volume (hatched line).
- VAE represents the “alveolar ejection volume” (true alveolar gas mixing volume).

**Uses of Volumetric Capnography**

- **Pulmonary Embolism**
  - 650,000 cases/year in US
  - 50,000 to 200,000 die.
  - Most deaths occur within first hour.
    - Prompt therapy can reduce mortality from 30% to 2.5 to 10%.
    - 70% of deaths from PE identified by autopsy were not identified before death.
- **Methods of PE detection**
  - Evaluation of V̇A/V̇t
  - Paco₂-Peto₂ gradient with maximum exhalation.
  - Late deadspace fraction (Ḟdlate)

**Uses of Volumetric Capnography**

- **Non-Invasive Cardiac Output**
  - Fick Principle (1870)
  - $Q_c = \frac{V O_2}{CaO_2 - CvO_2}$
  - OR $Q_c = \frac{V CO_2}{CvCO_2 - CaCO_2}$
Partial Rebreathing Method

• If we measure the VCO₂ and arterial CO₂ contents (substituting in end-tidal values for arterial and applying a solubility coefficient conversion), we can determine the cardiac output.

• If we then allow for rebreathing of CO₂ and allow for a change the VCO₂ and arterial (end-tidal) CO₂, we can determine the amount of change in these values.

• The ratio of the change in VCO₂ to that of arterial CO₂ is equivalent to the Cardiac Output.

• The difference in venous CO₂ values is ignored as it is determined by the amount of CO₂ that is returned to the lungs, which is constant.

Calculation involved with NICO

\[
 Q_c = \frac{\dot{V}CO_2}{CvCO_2 - CaCO_2}
\]

\[
 Q_c = \frac{\Delta \dot{V}CO_2}{\Delta PetCO_2}
\]

Other uses for Capnography

• During Apnea Testing in Brain-dead patients.  
  • Eur J Anaesthesia Oct 2007, 24(10):868-75  

• Evaluating DKA in children.  
  • No patients with a PetCO₂ >30 had DKA.  
  • J Paeditr Child Health Oct 2007, 43(10):677-680

• V̇e/V̇, ratio and ARDS Mortality  
  • Elevated V̇e/V̇ early in the course of ARDS was correlated with increased mortality.  
  • Chest Sep 2007, 132(3): 836-842

• PCA Administration  
  • “Continuous respiratory monitoring is optimal for the safe administration of PCA, because any RD event can progress to respiratory arrest if undetected.”  
  • Anesth Analg Aug 2007, 105(2):412-8