Non-Invasive Assessment of Respiratory Function

Chapter 11
Pulse Oximetry

- Laboratory measurements of ABG’s are the “gold standard” for measuring levels of hypoxemia, however since these are performed intermittently may fail to detect hypoxic episodes.
- Pulse oximetry provides continuous noninvasive measurements of arterial oxygen saturation:
  - Spectrophotometry estimates the amount of oxygen bound to Hb
  - Optical plethysmography estimates the pulse rate
Pulse oximetry

- Generally accurate for oxygen saturations >80%
- <80% needs to be confirmed by co-oximetry
- Excellent trending device for critically ill patients, useful for FiO2 and/or PEEP titration

Accuracy is affected by:
- Low perfusion states
- Dysfunctional Hb
  - Reduced/de-oxygenated (HHb)
  - Oxyhemoglobin (O2Hb)
  - Carboxyhemoglobin (COHb)
  - Methemoglobin (MetHb)
- Dyes (intravascular)
- Nail Polish
- Skin pigmentation
  - Typically higher with dark pigmentation
- Ambient light
Oxyhemoglobin Dissociation Curve
relationship between SaO2 and PaO2
You are preparing a patient for bronchoscopy. While administering an aerosol treatment with benzocaine, you note that the patient appears to be cyanotic, although the person does not show any signs of distress. Pulse oximetry readings indicate that the SpO2 is 85%. You immediately obtain ABG analyses which show pH 7.36, PaCO2 42, PaO2 80. Explain the etiology of the cyanosis. What diagnostic test would confirm this explanation?

The patient had an adverse reaction to the benzocaine and developed methemoglobinemia, which could be verified by performing CO-oximetry (allows direct measurement of methemoglobin levels in the patient's blood). Acute methemoglobinemia is treated with intravenous administration of methylene blue.
Capnography/Capnometry

• Capnography - continuous display of CO2 concentrations as a graphic waveform

• Capnometry - display of exhaled CO2 numerically without a waveform
Capnography/Capnometry

Chemical Methods
• Hand held devices
• Color changes on filter paper
• Useful in emergent situations – assess airway placement
• Secretions on the filter paper will render the device unusable

IR Spectroscopy
• Concentration of CO2 in a gas is directly related to the amount of IR light absorbed
• Pressure broadening – nitrous oxide N2O, H2O adversely affects the accuracy of CO2 measurements, erroneously high CO2 readings
• Sidestream sampling vs mainstream sampling
Capnogram

- Phase 1 – initial gas exhaled from the conducting airways (A-B)
- Phase 2 – alveolar air (B-C)
- Phase 3 – the curve plateaus as alveolar gas is exhaled (alveolar plateau) (C-D)
- PetCO2 end tidal PCO2 (D)
- Phase 4 – inspiration (D-E)
PetCO2

- Depends on alveolar PCO2
- Fever, sepsis, hyperthyroidism, and seizures increase the metabolic rate and VCO2
- Hypothermia, starvation, and sedation reduce the metabolic rate and VCO2
- Normally about 4-6mmHg lower than PaCO2
Normal Capnography
Capnography

• Changes in the contour of the capnogram can be used to detect increase in dead space ventilation, hyperventilation and hypoventilation, apnea or periodic breathing, inadequate neuromuscular blockade in paralyzed patients, and CO2 rebreathing.

• Monitors effectiveness of gas exchange during CPR and detects accidental esophageal intubation

• P(a-et)CO2 = 4-6mmHg
  – Elevated in COPD, left heart failure, pulmonary embolism
Understanding the Waveform
• Sudden loss of waveform to zero or near zero indicates that no breath is detected
• Possible causes
  – Total airway obstruction
  – Apnea
  – Kinked or displaced adaptor
• Absent alveolar plateau indicates incomplete alveolar emptying or loss of airway integrity
• Possibly caused by
  – Partial airway obstruction caused by secretions, tongue, or position of head - snoring
  – Hypoventilation due to decrease tidal volume
  – Talking – non emergent
- Increased EtCO2
- Possibly caused by:
  - Hypoventilation due to analgesia or sedation
  - Low RR or very shallow breathing
  - Rising body temperature
• Hypoventilation with shallow respirations
• Shallow breathing followed by a deep breath with full gas exchange taking place
Gradual decrease in EtCO₂ with normal waveform indicates a decreasing CO₂ production, or decreasing systemic or pulmonary perfusion

- Possibly caused by
  - Hypovolemia
  - Decreasing cardiac output
  - Hypothermia (decrease in metabolism)
  - Hyperventilation
• Rebreathing
• Results from rebreathing carbon dioxide, capnogram fails to return to baseline
• Possible causes
  – Draping near the airway
  – Poor head-neck alignment
  – Shallow breathing – not clearing deadspace
  – **Oxygen flow to mask too low**
• Classic hypoventilation
  – Resembles normal waveform: longer and higher (↑ EtCO$_2$ + ↓ RR)
  – Slower breathing with normal gas exchange
Cardiac oscillations

- During bradypnea phase 4 often shows the transfer of motion of the beating heart to the conducting airways
“Curare Cleft”

- Positive sign that the patient is receiving insufficient neuromuscular blockade or waking up post-op
Comparison of ETCO2 Waveforms

![ETCO2 Waveforms](image)
With considerable difficulty, an ETT is inserted without visualization of the trachea into a patient’s airway during cardiopulmonary resuscitation. Capnography results show a PetCO2 of 3mmHg; a standard ABG measurement shows a PaCO2 of 75mmHg. Explain the cause of this discrepancy in the capnography and ABG results.

Capnography is often used to assess placement of the ETT. In this case the tube was placed in the esophagus, preventing detection of any exhaled CO2. This finding can be confirmed by listening to breath sounds and examining chest radiographs.
Transcutaneous Monitoring –
modified blood gas electrodes to measure the O2 and CO2 tensions

Transcutaneous PO2
• Clark Electrode
• Unreliable for critically ill adults
• Hypoperfusion or increased vascular resistance cause erroneous results

Transcutaneous PCO2
• Stowe-Severinghaus electrode
• PtcCO2 values are slightly higher than PaCO2 values without correction factors
Technical Considerations

- Electrolyte solution and membrane
  - Ensure adequate solution
  - Changed weekly or PRN
  - Silver deposits require periodic cleaning

- Cleanse skin site: alcohol or shaving as needed

- Two point calibration: PtcO2 (RA 150mmHg = high; electronic zero = low) PtcCO2 (5% CO2 = low; 10% CO2 = high)

- Data should include date, time, activity level, body position, and site of placement

- Must be vigilant for burns, reposition q4-6hr
Indirect Calorimetry

• Allows the clinician to estimate energy expenditure from measurements of O2 consumption and CO2 production
• Based on the theory that all the energy the body uses is derived from the oxidation of carbohydrates, fats, and proteins and that the ratio of CO2 produced to O2 consumed (the respiratory quotient - RQ) is characteristic for the particular fuel burned
• Devices to measure this are called metabolic monitors or carts
Indirect Calorimetry

- Gas analysis will not reflect the underlying physiology accurately if a leak is present, such as a bronchopleural fistula or ETT cuff leak.
- Provides information on energy expenditure and the pattern of substrate utilization.
- The metabolic rate is affected by:
  - the type and rate of food ingested
  - the time of day the measurement is done
  - Whether the person is recovering from surgery, infection, or trauma
- Substrate utilization pattern – the proportion of carbohydrates, fats, and proteins that contribute to the total energy metabolism.
RQ

- Fat = 0.7
- Carbohydrates = 1
- Protein = 0.8
- RQ > 1 = lipogenesis
- RQ > 0.7 ketosis
- Helpful for weaning patients with limited ventilatory reserve from mechanical ventilation
  - High % of carbohydrates raises the VCO2 more that the VO2, added CO2 load is greater than ventilatory capacity
  - Switching to a diet with a higher fat-carbohydrate ratio lowers the VCO2/VO2 ratio reducing the CO2 load to lungs
Airway Pressure Measurements

• Measuring near the airway opening minimizes the effects of airway resistance
• PIP: maximum pressure generated during inspiration
• Pplat: amount of pressure required to maintain the Vt in the patient’s lungs during a period of no gas flow, reflects the alveolar pressure
Flow Measurement

• Vortex ultrasonic flowmeters use resistive elements to create a pressure drop proportional to the flow of gas

• Variable orifice pneumotachometers are disposable, bidirectional flow measuring devices

• Turbine flowmeters use a rotating vane place in the path of gas flow
Clinical Applications

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