ETCO₂ and Opioids: Measurement of the Ebb and Flow

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Capnography & EtCO₂

- Definition:
  - Capnography
    - Noninvasive, continuous measurement of inhaled and exhaled CO₂ concentration over time
  - EtCO₂
    - Level of CO₂ in the air exhaled from the body, the normal values of which are 4% to 6%, that is equivalent to 35 to 45 mm Hg

- Measures ventilation

Oxygen Saturation vs. Capnography

<table>
<thead>
<tr>
<th>Oxygen Saturation</th>
<th>Capnography</th>
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<tbody>
<tr>
<td>Measures oxygen available for metabolism</td>
<td>Measures carbon dioxide from metabolism</td>
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<tr>
<td>SpO₂ measures % of O₂ in RBC</td>
<td>EtCO₂ measures exhaled CO₂ at point of exit</td>
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<tr>
<td>SpO₂ changes lag with hypoventilation or apnea</td>
<td>Hypoventilation/apnea detected immediately</td>
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<tr>
<td>Should be used with capnography in certain situations</td>
<td>Should be used with SpO₂ monitoring</td>
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Oxygenation vs. Ventilation

An EKG
- Numeric reading: HR 100
- Waveform:

Another EKG
- Numeric reading: HR 100
- Waveform:
Uses for Capnography

- Assist in confirmation and monitoring of intubation
- Assess ventilation status
  - General Anesthesia
  - Moderate Sedation
  - Opioid Usage
    - PCA
    - Oral or IV
- Assist in assessment of perfusion
- Assess the effectiveness of CPR
- Assess response to treatment
- Documentation

Physiology of Oxygenation and Ventilation

- Five steps
  1. \( \text{O}_2 \) is inhaled into the lungs.
  2. \( \text{O}_2 \) is carried to cells via arterial blood.
  3. \( \text{O}_2 \) combines with glucose to form energy.
  4. \( \text{CO}_2 \) is formed as a byproduct of energy and returned to the lungs.
  5. \( \text{CO}_2 \) is eliminated in exhaled breath and measured by \( \text{EtCO}_2 \).

The Aveolar Capillary Membrane

- Arterioles divide at the terminal bronchioles to form a network of pulmonary capillaries
- Capillary walls often fuse with the basement membrane of the alveolar septum
- There is minimal separation between capillary blood and gas in the alveolus
- Gas exchange occurs across the alveolar-capillary membrane (the shared alveolar and capillary walls)
End-tidal CO₂ (EtCO₂)

- Normal a-A gradient
  - 2-5 mmHg difference between the EtCO₂ and PaCO₂ in a patient with healthy lungs
  - Wider differences found
    - In abnormal perfusion and ventilation
    - Incomplete alveolar emptying
    - Poor sampling
End-tidal CO₂ (EtCO₂)

- Monitors changes in
  - Ventilation - asthma, COPD, airway edema, foreign body, stroke, respiration depression
  - Diffusion - pulmonary edema, alveolar damage, CO poisoning, smoke inhalation
  - Perfusion - shock, pulmonary embolus, cardiac arrest, severe dysrhythmias

What’s the Problem?

- According to the U.S. FDA database (through Jan 2011), there were 4,230 reports on PCA-related events in which 826 (19.5%) resulted in injury or death.

Risk of Respiratory Depression

- Respiratory depression from the administration of pain medication is a leading cause of preventable death in hospitals, creating an increasing source of medical liability. "More than half (52 percent) of jury awards in medical liability cases now exceed $1 million and the average award is $4.7 million."1

- Postoperative respiratory failure is the third most common patient safety incident in hospitals each year, affecting an estimated 600,000 patients at a cost of $1.5 billion.2

- Relying on respiratory rate and/or pulse oximetry to detect respiratory distress, without measuring exhaled CO₂, leaves patients at risk for respiratory failure.3
Why is Capnography so important?

- It is becoming a standard of care.
- 2010 AHA/ERC Resuscitation Guidelines
  - Continuous quantitative waveform capnography is now recommended for intubated patients throughout the periarrest period.
- American Society of Anesthesiologists, Standard 3.2.4
  - Effective July 1, 2011, Basic Anesthetic Monitoring Standard 3.2.4., requires: “...During moderate or deep sedation, the adequacy of ventilation shall be evaluated by continual observation of qualitative clinical signs and monitoring for the presence of exhaled carbon dioxide unless precluded or invalidated by the nature of the patient, procedure, or equipment.” (ASA, 2010)
- Anesthesia Patient Safety Foundation (APSF) advocates monitoring both oxygenation and ventilation in all patients receiving PCA (Stoelting & Overdyk, 2011)

What does ASPMN Say?

- “At this time, the ASPMN Expert Consensus Panel recommends that the use of pulse oximetry and capnography to detect respiratory compromise in the ongoing care of patients who are receiving continuous opioid therapy be determined by patient risk factors, iatrogenic risk, and institutional policies.” (Jarzyna et al., 2011)

Recent Research on Oxygenation vs. Capnography

- In patients receiving supplemental oxygen, oxygen saturation may remain normal for at least 3 minutes after the patient stops breathing (Carroll et al., 2002)
- Capnography resulted in greater detection of respiratory depression than pulse oximetry in 54 opioid-naive post-op patients (Hutchison, 2008)
- Capnography identified that alveolar hypoventilation occurred in 56% of endoscopy procedures vs 3% identified by pulse oximetry and visual monitoring (Lightdale, 2006)
- Capnography provided early warning of ventilatory abnormalities, alerting physicians to respiratory depression before onset of hypoxic event (Deitich et al., 2010)
Capnograph Display
1. Numerical Value for EtCO$_2$
2. Provides a waveform for each respiratory cycle – a capnogram

Capnography Options
Low-flow sidestream technology
- In sidestream capnographs, the exhaled CO$_2$ is aspirated via ETT, cannula, or mask, through a 5–10 foot long sampling tube connected to the instrument for analysis; this method is intended for the non-intubated patient.

EtCO$_2$ Monitoring
- In sidestream capnographs the exhaled CO$_2$ is aspirated via ETT, cannula, or mask, through a 5–10 foot long sampling tube connected to the instrument for analysis; this method is intended for the non-intubated patient.
VALUE OF WAVEFORMS

- Visual assessment of patient airway integrity
- Height shows amount of exhaled carbon dioxide
- Length depicts time
- The shape of a capnogram is identical in all humans with healthy lungs.
- Any deviations in shape must be investigated to determine a cause of the abnormality

A Normal Waveform

- Waveforms have a characteristic shape like an ECG
- Inhalation and exhalation of CO₂ give a characteristic shape
- During exhalation, and inhalation of CO₂ free gases
- Normal CO₂ waveforms must have all of these components:
  - A-B: Baseline = no CO₂ in breath
  - B-C: Exhalation begins, rapid rise in CO₂
  - C-D: Alveolar plateau
  - D: End of expiration (end tidal)
  - D-E: Inhalation

Normal Values

- Normal PaCO₂ from an ABG sample is 35 - 45 mmHg
- Normal EtCO₂ is between 30 – 45 mmHg
- EtCO₂ under normal conditions can be 2 to 5 mmHg lower than an arterial PaCO₂ on an arterial blood gas sample.
- Fractional Inspired Carbon Dioxide (FiCO₂) is 0 mmHg; This is the “0” baseline on the capnogram
- Adult respiratory rate – 8 to 24
- Pediatric respiratory rate – 12 to 60 (age dependent)
FACTORS AFFECTING EtCO₂

INCREASED EtCO₂

• Mechanical
  – Excessive mechanical dead space
  – Faulty exhalation valve

• Respiratory
  – COPD
  – Respiratory depression
  – Respiratory insufficiency

• Circulatory
  – Increased cardiac output
  – Increased activity
  – Tourniquet release

• Metabolic
  – Hyperthermia

INCREASED EtCO₂

LOW EtCO₂

• Mechanical
  – Circuit disconnect
  – Circuit leaks
  – Sampling system leak

• Respiratory
  – Airway obstruction
  – Bronchospasm
  – Displaced ET tube
  – Hyperventilation
  – Mucus plug in airway

• Circulatory
  – Cardiac arrest
  – Embolism
  – Sudden hypovolemia

• Metabolic
  – Hypothermia

Capnography in Bronchospastic Conditions

• Air trapped due to irregularities in airways
• Uneven emptying of alveolar gas
  – Dilutes exhaled CO₂
  – Slower rise in CO₂ concentration during exhalation
Partial Obstruction

- Clinical findings:
  - Irregular breathing, possible snoring or audible breathing
  - EtCO₂ may be above or below baseline
- Possible causes:
  - Poor head or neck alignment
  - Overmedication or sedation
- Possible responses:
  - Follow hospital protocol
  - Assess ABC’s
  - Perform head-tilt/chin lift
  - Encourage deep breaths
  - Check position of cannula
  - Notify prescribing physician
  - Call the rapid response team if no improvement is noted

Kraft, 2010

No Breath

- Clinical findings:
  - Very shallow or no respiratory rate pattern
  - Sudden loss of EtCO₂ reading
- Possible causes:
  - No breath or apnea
  - Very shallow breathing
  - Overmedication or sedation
  - Displaced cannula
- Possible responses:
  - Follow hospital protocol
  - Assess ABC’s
  - Stimulate patient
  - Open airway
  - Notify prescribing physician
  - Call the rapid response team if no improvement is noted

Kraft, 2010

EtCO₂ Alarms

- Low EtCO₂ Alarm
  - Possible causes: true measurement, disposable not correctly attached to patient
- High EtCO₂ Alarm
  - Possible causes: true measurement, fever or hypermetabolic state, disposable not correctly attached to patient
- High FiCO₂ Alarm
  - Possible causes: pt. is inspiring exhaled CO₂, disposable not correctly attached to patient, oxygen flow to mask may have stopped, covers may be over patient’s face
- No Breath Detected Alarm
  - Possible causes: patient is not breathing, disposable not correctly attached to patient and/or device, disposable not detecting exhaled breath (shallow breath)
Relationship between EtCO₂ and RR

**Hyperventilation**
- ↑ respiratory rate = ↓ CO₂

**Hypoventilation**
- ↓ respiratory rate = ↑ CO₂

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Capnography Waveform Question

- How would your capnogram change if you intentionally started to breathe at a rate of 30?
  - Frequency
  - Duration
  - Height
  - Shape

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**Hyperventilation**
- ↑ respiratory rate = ↓ CO₂

[Diagram of capnography waveforms showing normal and hyperventilation conditions]
Hyperventilation

- Clinical findings:
  - Rapid breathing, low EtCO₂
- Possible causes:
  - Increase in pain level or splinting
  - Increase in anxiety or fear
  - Respiratory distress or shortness of breath
- Possible responses:
  - Follow hospital protocol
  - Assess ABC’s
  - Treat cause of increased RR
  - Decrease pain stimulus
  - Notify prescribing physician
  - Call the rapid response team if no improvement is noted

Waveform:

Regular Shape, Plateau Below Normal

- Indicates CO₂ deficiency
  - Hyperventilation
  - Decreased pulmonary perfusion
  - Hypothermia
  - Decreased metabolism
- Interventions
  - Adjust ventilation rate
  - Evaluate for adequate sedation
  - Evaluate anxiety
  - Conserve body heat

Capnography Waveform Question

- How would your capnogram change if you intentionally decreased your respiratory rate to 8?
  - Frequency
  - Duration
  - Height
  - Shape
Hypoventilation

↓ respiratory rate = ↑ CO₂

Waveform: Regular Shape, Plateau Above Normal

- Indicates increase in EtCO₂
- Clinical findings:
  - Slow breathing, high EtCO₂
- Possible causes:
  - Increased sedation, overmedication
  - Snoring or possible obstruction
- Possible responses:
  - Follow hospital protocol
    - Assess Airway, Breathing and Circulation (ABC’s)
    - Assess sedation level
      - Follow PCA orders to treat or reverse the cause
        (naloxone, romazicon)
      - Decrease opioids and/or benzodiazepines
      - Stimulate patient
    - Notify prescribing physician
    - Call the rapid response team if no improvement is noted

Hypoventilation in Shallow Breathing

- Clinical findings:
  - Slow breathing, low EtCO₂
  - Followed by deep breath
- Possible causes:
  - Increased sedation
  - Low tidal volume
    - Alveolar gas is not exhaled or is only partially exhaled
    - Dead space gas is exhaled with some alveolar gas
- Possible responses:
  - Same as previous slide
Case Study #1

• A 69 year-old healthy patient with a BMI of 25 is admitted to your unit following a total knee replacement.
• He received a femoral nerve block prior to OR.
• He is on a Morphine PCA postop: 2 mg dose, 6 minute lockout with a dose limit of 12 mg/hr.
• Two hours after initiating the PCA, his respiratory rate decreases to 8 breaths per minute and his EtCO₂ increases from 35 to 50 mmHg and he is slow to respond to verbal stimuli.

Discussion

• What treatments or interventions would be appropriate for this patient?
• What is the most likely cause of the observed distress?

Case #1 Cont.

• The PCA was restarted two hours later at 1 mg dose with a 6 minute lockout. The nurse noted his respiratory rate was 10 breaths/minute, EtCO₂ was 25 mmHg and he had minimal chest excursion. When he took a deep breath, the EtCO₂ increased to 58 mmHg. He was arousable to verbal stimuli and denied pain.
Case Study #2

• A 16 year-old trauma patient is experiencing shortness of breath.
• Pneumothorax, pulmonary embolism and pneumonia were all ruled out.
• He has been on a Fentanyl PCA dose of 15 mcg with a 15 minute lockout and a 90 mcg hourly dose.

Discussion

• What treatments or interventions would be appropriate for this patient?
• What is the most likely cause of the observed distress?
Case Study #3

• 60 year-old female admitted with back pain due to metastasis of breast cancer. PCA Morphine for pain control was started. After 2 hours, her pain score was 9/10. The PCA dose was increased to 2 mg with a lockout of 6 minutes and a continuous rate of 2 mg/hr was added.
• An hour later she was lethargic, respirations were shallow and irregular at a rate of 6, oxygen saturation was 68% and EtCO₂ was 72.

Capnography in Bronchospastic Diseases and Obstructive Diseases

• Uneven emptying of alveolar gas alters emptying on exhalation
• Produces changes in ascending phase (II) with loss of the sharp upslope
• Alters alveolar plateau (III) producing a "shark fin"

Why Use Capnography?

• The following patient conditions and alarm states can be observed using continuous EtCO₂ and SpO₂ monitoring and opioid administration:
  1. Opioid - induced apnea: detected by no breath alarm
  2. Undiagnosed sleep apnea: detected by no breath alarm
  3. Post-op pneumonia: detected by low oxygen saturation alarm
  4. Congestive heart failure: detected by low oxygen saturation alarm
  5. Respiratory depression secondary to opioid overdose: detected by all of the following:
     • Low oxygen saturation alarm
     • High EtCO₂ alarm
     • Low respiratory rate alarm
     • No breath alarm