Noninvasive Monitoring of Gas Exchange: Questions Answered

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Conflict of Interest

I have no real or perceived conflict of interest that relates to this presentation.

Any use of brand names is not in any way meant to be an endorsement of a specific product, but to merely illustrate a point of emphasis.
Objectives

- Describe the correlation of noninvasive monitoring and other physiologic measurements.
- Identify the technology available for noninvasive monitoring of gas exchange.
- Identify clinical areas in which noninvasive monitoring may help to improve patient assessment and treatment.
### Rationale

<table>
<thead>
<tr>
<th>Components</th>
<th>Physiologic Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pulmonary</strong></td>
<td>Ventilation</td>
</tr>
<tr>
<td><strong>Gas exchange</strong></td>
<td>AIR</td>
</tr>
<tr>
<td><strong>Oxygen delivery</strong></td>
<td>O₂</td>
</tr>
<tr>
<td><strong>Oxygen extraction</strong></td>
<td>Diffusion</td>
</tr>
<tr>
<td><strong>Oxygen consumption</strong></td>
<td>Ventilation-perfusion</td>
</tr>
<tr>
<td><strong>Cardiac output</strong></td>
<td>Perfusion</td>
</tr>
<tr>
<td><strong>Cvo₂</strong></td>
<td>Blood</td>
</tr>
<tr>
<td><strong>CaO₂</strong></td>
<td>Oxygen extraction</td>
</tr>
<tr>
<td><strong>O₂</strong></td>
<td>Oxygen consumption</td>
</tr>
<tr>
<td><strong>ATP</strong></td>
<td></td>
</tr>
</tbody>
</table>
Blood and Air

- Oxygenated blood
- Deoxygenated blood

Lungs

O_{2} → CO_{2}

O_{2} ← CO_{2}

External respiration

P_{O2} 160
P_{CO2} 0

Dry inspired air

Humidified bronchial air

P_{O2} 150
P_{CO2} 0

Alveolar air

Alveolus

CO_{2} → O_{2}

P_{aO2} 100
P_{aCO2} 40

Pulmonary Capillary

Mixed venous blood

P_{V}O_{2} 40
P_{V}CO_{2} 46

Systemic arterial blood

P_{a}O_{2} 100
P_{a}CO_{2} 40
Linking Oxygenation & Ventilation

- Increased affinity of hemoglobin for oxygen:
  - ↓[H+]
  - ↓PaCO₂
  - ↓T
  - ↓2,3 DPG
  - ↓Fetal Hb

- Decreased affinity of hemoglobin for oxygen:
  - ↑H+
  - ↑PaCO₂
  - ↑T
  - ↑2,3 DPG
  - ↑Adult Hb

% Oxygen saturation vs. Partial pressure of oxygen (mm Hg)
Vital Signs

♦ Heart Rate
♦ Blood Pressure
♦ Temperature
♦ Respiratory Rate
ABG vs. Continuous Monitoring

- Arterial Blood Gases
- Pulse Oximetry (SpO₂)
- Capnography (ETCO₂)
- Transcutaneous (SpO₂/CO₂)
Pulse Oximetry

Red and infrared diodes

Light sources

Photodetector

VASCULAR BED

Arterial Blood

Venous Blood

Tissue

SpO2 97%
SpO$_2$ Value

Hemoglobin-O$_2$ Binding Curve

% Saturation of Hemoglobin vs. $P_{aO_2}$ (mm Hg)

- 90% saturation at $P_{aO_2}$ of 40 mm Hg
- 97.5% saturation at $P_{aO_2}$ of 100 mm Hg

Hb-O$_2$ content (ml O$_2$/100 ml blood)

- 26 ml O$_2$/100 ml blood at 40 mm Hg
- 15 ml O$_2$/100 ml blood at 100 mm Hg
Equipment

Amazon search results for "pulse oximeter" with images of different pulse oximeters.
Breakthrough Measurements. Radical Monitor.

Radical-7

To learn more, click here >>
Probe Selection and Placement
Issues with Pulse Oximetry

- Normal Signal
- Low Perfusion
- Noise Artifact
- Motion Artifact
<table>
<thead>
<tr>
<th>Factor</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carboxyhemoglobin (COHb)</td>
<td>Slight reduction of the assessment of oxygen saturation (Sao₂) by pulse oximetry (Spo₂) (i.e., overestimates the fraction of hemoglobin available for O₂ transport)</td>
</tr>
<tr>
<td>Methemoglobin (MetHb)</td>
<td>At high levels of MetHb, Spo₂ approaches 85%, independent of actual Sao₂</td>
</tr>
<tr>
<td>Methylene blue</td>
<td>Transient, marked decrease in Spo₂ lasting up to several minutes; possible secondary effects as a result of effects on hemodynamics</td>
</tr>
<tr>
<td>Anemia</td>
<td>If Sao₂ is normal, no effect; during hypoxemia with Hb values less than 14.5 g/dL, progressive underestimation of actual Sao₂</td>
</tr>
<tr>
<td>Ambient light interference</td>
<td>Bright light, particularly if flicker frequency is close to a harmonic of the light-emitting diode switching frequency, can falsely elevate the Spo₂ reading</td>
</tr>
<tr>
<td>Blood flow</td>
<td>Reduced amplitude of pulsations can hinder obtaining a reading or cause a falsely low reading.</td>
</tr>
<tr>
<td>Motion</td>
<td>Movement, especially shivering, may depress the Spo₂ reading.</td>
</tr>
<tr>
<td>Nail polish</td>
<td>Slight decrease in Spo₂ reading, with greatest effect using blue nail polish, or no change</td>
</tr>
<tr>
<td>Sensor contact</td>
<td>“Optical shunting” of light from source to detector directly or by reflection from skin results in falsely low Spo₂ reading.</td>
</tr>
<tr>
<td>Skin pigmentation</td>
<td>Small errors or no significant effect reported; deep pigmentation can result in reduced signal.</td>
</tr>
<tr>
<td>Tape</td>
<td>Transparent tape between sensor and skin has little effect; falsely low Spo₂ has been reported when smeared adhesive is in the optical path.</td>
</tr>
<tr>
<td>Vasodilatation</td>
<td>Slight decrease</td>
</tr>
<tr>
<td>Venous pulsation</td>
<td>Artifactual decrease in Spo₂</td>
</tr>
</tbody>
</table>
THERMAL IMAGE OF A HEALTHY ADULT IN A COLD ROOM

EXTREMITIES VERSUS THE FOREHEAD

1–2 Minutes

45 Minutes
Practice Pearls

♦ When in doubt, feel for a pulse (signal strength matters)
♦ Consider SpO₂ a diagnostic tool
♦ Know the limitations of the technology
♦ Correlate patient condition with SpO₂ reading
♦ Use the right probe for the situation
♦ Know the technology (you are the expert)
Capnography: End Tidal CO₂
Capnography Clinical Applications

- Verification of ETT Placement
- CPR
- Trend ETCO$_2$
- Brain death study
- Conscious sedation
- Patient transport
- Deadspace measurement
SpO$_2$ versus ETCO$_2$

**Pulse Oximetry**
- Oxygen saturation
- Reflects oxygenation
- SpO$_2$ changes lag when patient is hypoventilating or apneic
- Should be used with capnography

**Capnography**
- Carbon dioxide
- Reflects ventilation
- Hypoventilation or apnea detected immediately
- Should be used with pulse oximetry
Equipment

EtCO₂

38 mmHg

Resp

12 min⁻¹
Deadspace
PULMONARY DEAD-SPACE FRACTION AS A RISK FACTOR FOR DEATH IN THE ACUTE RESPIRATORY DISTRESS SYNDROME


Figure 1. The Observed Mortality According to the Quintile of Dead-Space Fraction in 179 Patients with the Acute Respiratory Distress Syndrome.
• Waveform / colorimetric device for ETT placement verification.
• Use as a guide for mechanical ventilator management.
• Use during transport of intubated patient.
• Identification of exhalation abnormalities.
• Measure and manage Vd/Vt.
• Use during CPR.
Capnography Practice Pearls

- ETCO$_2$ – PaCO$_2$ gradient reflects degree of deadspace and lung impairment.
- Sections and fluid interfere with signal.
- Minimize patient/ventilator disconnections.
- Low ETCO$_2$ values indicate trouble.
- Changes over time as patient changes.
- Issues are usually the patient, not the monitor.
- Chasing normal values may not be possible.
TC Monitoring of Gas Exchange

- Transcutaneous monitoring measures skin-surface PO$_2$ and PCO$_2$.
- Induces hyperperfusion by local warming of the skin.
- Measures partial pressure of oxygen and carbon dioxide electrochemically.
- Need to monitor the adequacy of oxygenation & ventilation in all patient populations.
- Need to measure the response to diagnostic & therapeutic interventions.
Transcutaneous Monitoring
Transcutaneous Sensor

Selection of Patient Type, Measurement Site and Sensor Attachment Accessory

‘Adult’ if Older than Term Birth + 1 Month

‘Neonatal’ if Younger than Term Birth + 1 Month

○ PCO₂

○ PCO₂ / SpO₂ / Pulse Rate

• application area
<table>
<thead>
<tr>
<th>Department</th>
<th>Department</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dermatology</td>
<td>ENT</td>
</tr>
<tr>
<td>Radiation Oncology</td>
<td>ED</td>
</tr>
<tr>
<td>Bronch Suite</td>
<td>GI</td>
</tr>
<tr>
<td>General surgery</td>
<td>Urology</td>
</tr>
<tr>
<td>Interventional radiology</td>
<td>Dentistry</td>
</tr>
<tr>
<td>Interventional cardiology</td>
<td>???</td>
</tr>
</tbody>
</table>
Conscious Sedation

♦ Planning the Administration of Moderate or Deep Sedation or Anesthesia
♦ “Depth & Adequacy of Respiration”
♦ Usually done with 3 lead ECG & SpO$_2$
♦ May trigger Rapid Response Team activity
NPPV and HFNC
Transcutaneous vs Capnography
EVALUATION OF A NEW DIGITAL TRANSCUTANEOUS \( \tau_{C} PCO_2 \) & \( S_F O_2 \) COMBINATION SENSOR AND ITS CORRELATION TO ABG \( P_a CO_2 \) MEASUREMENTS

Daniel D. Rowley, BS, RRT-NPS, RPFT, Brian K. Walsh, BS, RRT-NPS, RPFT, Barry Young, BS, RRT, Frank J. Caruso, BS, RRT

Pulmonary Diagnostics and Respiratory Therapy Services
University of Virginia Health System, Charlottesville, Virginia
Concordance between transcutaneous and arterial measurements of carbon dioxide in an ED
Accuracy of transcutaneous CO₂

Range 17-109 mm Hg
Heart failure, pneumonia, asthma, COPD

# Techniques for the Measurement and Monitoring of Carbon Dioxide in the Blood

<table>
<thead>
<tr>
<th>Criterion</th>
<th>ABG</th>
<th>CBG</th>
<th>VBG</th>
<th>Capnography/ Capnometry</th>
<th>Ptc\textsubscript{CO}_2</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Gold standard”</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Accurate</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Continuous</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Noninvasive</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Painless</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Without puncture damage</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Without blood loss</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Rapid results/no delay</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Additional parameters*</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Nonskilled staff</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Standard venous blood sample</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>No technical drift</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Valid with perfusion–ventilation mismatch</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Independent from leakage</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>No sleep disturbance</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Independent from dermal perfusion</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>No artificial airway necessary</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>
1. Correlate with ABG
2. Use to assess adequacy of ventilation
3. Use to assess tissue perfusion
4. Avoid thick skin/edema
5. Rotate sensor sights
6. Follow manufacturer recommendations
Transcutaneous Monitoring

- Neonatal to Adult population
- Sensor sites are plentiful
- Monitoring TcPCO$_2$ has appeal
- Technology has arrived
- Correlation studies have been DONE!!!!
- Help decide ABG sampling timing
- Reduce ABG samples
- Accurate data leads to clinical decisions
Summary

- Monitoring ensures rapid detection of changes in the clinical status.
- Allows for accurate assessment of progress and response interventions.
- Use non-invasive techniques when possible.
- Monitoring is crucial for patient safety.
Thanks for your attention!