Empowering the RT with New Noninvasive Monitoring Capabilities

Thomas Lamphere  BS, RRT, RPFT

Executive Director, Pennsylvania Society for Respiratory Care
Adjunct Instructor, Respiratory Care Program, Gwynedd Mercy College
Staff Therapist, Grand View Hospital, Sellersville, PA
Conflict of Interest

- I have affiliations with, special interests, or have conducted business with the following companies that in context with this presentation might possibly constitute a real or perceived conflict of interest:

- Masimo, Inc. (honorarium for lecture)
Scenario..

54 year old patient admitted to Emergency Room with increasing dyspnea and mild stomach pain over the past week.

- Bilateral breath sounds are clear w/ good aeration.
- Pulse oximetry reveals an SpO2 = 97% on room air.
- ABG is drawn -->

  pH = 7.48  PaCO2 = 35  PaO2 = 96  HCO3 = 24  SaO2 = 97%

Subsequent CBC reveals the patient’s Hgb = 6.2 and the patient is diagnosed with a GI bleed.
What IS Hypoxemia??

Always Start at the Beginning...
Pop Quiz!
Question #1

In a healthy, resting adult, what is the amount of oxygen required by the tissues & cells each minute?

A) 100 ml
B) 150 ml
C) 200 ml
D) 250 ml
E) I need another cup of coffee to remember…
How Much O₂ Do We Need?

> Normally, tissues require approximately 250 ml of oxygen *per minute* at rest.
Transportation of Oxygen

- Oxygen is transported in the blood in two ways:
  1. Dissolved in the plasma
  2. Attached to the hemoglobin

- The amount of oxygen dissolved in the blood follows Henry’s law, so the amount dissolved into the blood is proportional to the partial pressure of oxygen.
Dissolved Blood Oxygen (PaO2)

- For every 1 mmHg of PO2, .003ml O2/dl (100ml) diffuses into the blood. Normal PaO2 = 100 so .3 ml diffuses per dl = 3 ml of O2 per liter (of blood)

- Assuming a cardiac output of 6 L/min, the total oxygen delivery would be 18 ml/min.....which is 232ml/min less than what is needed!

- Therefore…life cannot be sustained by PaO2 alone.
Oxygen Bound to Hemoglobin

- Red blood cells contain the protein hemoglobin.
- Each hemoglobin molecule has four heme groups.
- Oxygen binds loosely and reversibly to these groups.
- Each gram of hemoglobin can carry 1.34 ml of oxygen.
Oxygen Bound to Hemoglobin

- A normal hemoglobin level is approximately 15g/dl
- If every heme binding site had O2 attached, the total O2 bound to Hgb = $15 \text{ g/dl} \times 1.34 \text{ ml} = 20.1 \text{ ml/dl}$
- Assuming a C.O. of 6 L/min, the total O2 bound to Hgb = 1,206 ml.
- Normally, the heme binding sites are only 97-98% saturated so… $1,206 \times .97 = 1,170 \text{ ml}$
- $1,170 \text{ ml (Hgb)} + 18 \text{ ml (diffused)} = 1,188 \text{ ml/min}$
Although the PaO2 is important (a low PaO2 would result in less oxygen available to bind to Hgb) 98% of the oxygen delivered to the cells is thanks to the Hgb.
All of this sounds familiar...
Total Oxygen Content

\[ CaO2 = (1.34 \times Hgb \times SaO2) + (PaO2 \times 0.003) \]

- \( CaO2 \) = total oxygen content
- 1.34 is the amount of O2 each gram of Hgb can carry
- Hgb is the total amount in the blood
- SaO2 is the % of heme sites saturated with O2
- 0.003 is the amount of O2 diffused per 1 mmHg of PaO2
What Is Considered Anemia?

- World Health Organization Definition of Anemia

  Children aged 6 months to 5 years: 11 g/dl
  Children aged 5-11 years: 11.5 g/dl
  Children aged 12-14 years: 12.0 g/dl
  Adult (non-pregnant) Females: 12.0 g/dl
  Adult (pregnant) Females: 11 g/dl
  Adult Males: 13 g/dl

Types of Hemoglobin

- Oxyhemoglobin (HbO2) - fully saturated with oxygen
- Reduced hemoglobin (Hb) - not fully saturated with oxygen
- Carboxyhemoglobin (COHb) - saturated with carbon monoxide
- Methemoglobin (MetHb) - ferrous component of iron in hemoglobin is changed to the ferric form.
Effect of Hgb on Patient Care

Emergency Room

- **Anemia** - can lead to dyspnea, hypotension, cardiac events
- **Carboxyhemoglobinemia** - caused by clogged chimney / heater malfunction, space heater, power generator, suicide

Intensive Care Unit

- **Post-Operative Care** - monitoring for internal bleeding.
Effect of Hgb on Patient Care

Operating Room
- Pre-operative check
  - Rescheduling of surgery if Hgb is too low
- Intra-surgery Hgb monitoring
  - Blood loss = increased mortality risk

Outpatient Areas
- Pulmonary Function Lab
  - Effect on Single Breath Diffusing Capacity
  - Pulmonary Stress Testing
Measurement of Hgb
Pop Quiz!
Question #2

How many methods currently are in use to measure a patient’s hemoglobin level?

A) 2
B) 3
C) 4
D) 5
Measurement of Hgb - What’s Available???

1. Hematology Analyzer (CBC)
2. CO-oximeter
3. Point of Care Analyzer
4. Non-Invasive Pulse CO-Oximetry
Hematology Analyzer

- Most commonly performed blood test
- Utilizes either cyano-methemoglobin reaction or newer technology that utilizes sodium lauryl sulfate along with spectrophotometry
- Provides information on the number of RBCs, WBCs, Platelets, Hgb and more….
- Requires blood sample (typically 10-15ml)
- Entire time from sampling to results varies based on numerous variables and can range from 20 minutes to several hours.
CO-oximetry

- Utilize spectrophotometric detection and multiple wavelengths of light
- Considered by many as the “gold standard” as variant forms of Hgb can be measured (COHb, MetHb, etc.)
- Requires blood sample (typically 1-3ml)
- Analysis time is short (1 minute) but sampling, transport and reporting time can add to total reporting time of results.
Point of Care Analyzer

- iSTAT analyzer measures Hct based on electrical conductance. The measured conductivity, after correction for electrolyte concentration, is inversely related to the hematocrit.

- Hgb is then calculated by:

\[
\text{Hemoglobin (g/dL)} = \text{hematocrit} \times 0.34
\]
Point of Care Analyzer

- The HemoCue Hb 201 analyzer utilizes a chemically pretreated cuvette for the blood sample.

- The reagents deposited on the inner wall of the cuvette lyse the red cells and convert Hb into azide methemoglobin.

- The Hb concentration is calculated by using spectrophotometric analysis with two wavelengths of light.
Non-Invasive Hemoglobin Monitoring

Two Technologies

- Masimo’s “Rainbow Pulse CO-Oximetry” technology utilizes 8 wavelengths of light to determine levels of carboxyhemoglobin, methemoglobin, and total hemoglobin.

- OrSense’s “Occlusion Spectroscopy” monitors the change in time of the optical characteristics of blood, controlling the blood flow or stopping it. This stoppage triggers changes in the blood that can be monitored and give readings of hemoglobin levels.
I Hate Choices!!!!
Weighing the Pros & Cons....
Hematology Analyzer (HA)

- **Advantages**
  1. Accurate
  2. Provides results for WBC, platelets, more!

- **Disadvantages**
  1. Invasive / Risk of infection
  2. Takes time (sampling, transport, analysis)
  3. Expense (analyzers, personnel, supplies)
  4. Unable to identify abnormal Hgb
  5. Can be difficult to obtain sample
  6. Opportunities for error (sampling, analysis)
CO-oximetry

- **Advantages**
  1. Accurate
  2. Measures Total Hb, COHb, metHb, oxyHb
  3. Often part of ABG analyzer

- **Disadvantages**
  1. Invasive / Risk of infection
  2. Takes time (sampling, transport, analysis)
  3. Expense (analyzers, personnel, sampling supplies)
  4. Can be difficult to obtain sample
  5. Opportunities for error (sampling, analysis)
Point of Care Analyzers

**Advantages**
1. Accurate
2. Smaller sample size
3. Bedside sampling & analysis
4. Can be included with other analytes

**Disadvantages**
1. Invasive / Risk of infection
2. Expense (analyzers, supplies, cartridges)
3. Unable to identify abnormal Hgb
4. Can be difficult to obtain sample
5. Opportunities for error (sampling, analysis)
Non-Invasive Hemoglobin Monitoring

- **Advantages**
  1. Easy to perform
  2. Non-invasive
  3. Continuous Trending
  4. Accurate
  5. Can measure COHb, metHb (Masimo only)
  6. Non-Invasive SpOC

- **Disadvantages**
  1. Expense (devices, sensor probe)
  2. Only one FDA cleared technology as of 11/11
Pop Quiz!

Question #3

Which of the following methods of measuring hemoglobin is the most accurate?

A) CO-oximeter
B) Point of Care Analyzer
C) Pulse CO-Oximetry
D) Hematology Analyzer
Accuracy

- Hematology analyzers are the most accurate but cannot identify abnormal Hgb.

- CO-oximeters are also accurate. However, studies have shown that intra-device variability for Hgb exists. (Intradevice comparison is variability from the same blood sample on the same device.)
Intradevice Comparison of CO-oximeters

<table>
<thead>
<tr>
<th>Intradevice Comparison</th>
<th>Brand A</th>
<th>Brand B</th>
<th>Brand C</th>
<th>Brand D</th>
<th>Brand E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (g/dl)</td>
<td>-0.8</td>
<td>-0.3</td>
<td>-0.4</td>
<td>0.0</td>
<td>0.4</td>
</tr>
<tr>
<td>Standard deviation (g/dl)</td>
<td>0.3</td>
<td>0.2</td>
<td>0.9</td>
<td>0.1</td>
<td>1.2</td>
</tr>
</tbody>
</table>

n = 36 patients   Two identical analyzers used per brand

## CO-oximeter Variation vs Control

<table>
<thead>
<tr>
<th>Intradevice Comparison</th>
<th>LEVEL 1</th>
<th>LEVEL 2</th>
<th>LEVEL 3</th>
<th>LEVEL 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Hgb of Control (g/dL)</td>
<td>5.4</td>
<td>8.4</td>
<td>13.8</td>
<td>17.4</td>
</tr>
<tr>
<td>Standard Deviation: All Devices (g/dL)</td>
<td>0.3</td>
<td>0.3</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>Range Level (g/dL)</td>
<td>5.0-5.4</td>
<td>8.0-8.6</td>
<td>13.3-14.2</td>
<td>17.1-17.7</td>
</tr>
</tbody>
</table>

31 oximeters from 5 different manufacturers

RNA Medical. CVC 223 CO-oximeter Calibration Verification Controls. RNA Medical, Division of Bionostics. Devens, WA 01434.
Point of Care (POC) CO-oximetry

- Studies have shown POC analysis results can vary from 0.5-2.3 g/dL \(^1-^6\)

1 - Science. 2007;36:235-242
2 - JECT. 2007;39:10-17
3 - Inten Care Med. 2007; 33:355-358
4 - ASAIO J. 2001;47(3):240-3
6 - Am J Clin Nutr 1999 ;69 :1243-8
Pop Quiz!

Question #4

How many non-invasive devices are currently in production world-wide?

A) 2
B) 4
C) 5
D) 6
Non-Invasive Hemoglobin Monitoring

- Six commercial non-invasive devices are currently in production:
  
**NBM 200MP**
- CE approved
- Not currently FDA cleared

**Masimo Radical-7, Rad-87, Rad-57, Pronto, Pronto-7**
- FDA cleared
Accuracy – Masimo SpHb

- n = 492
- CC = 0.90
- SD = 0.95 g/dL
## Accuracy – Masimo SpHb Study Results for FDA Submission

<table>
<thead>
<tr>
<th>tHb Range</th>
<th>Difference Between SpHb and tHb N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10 g/dL</td>
<td>≤1.0 g/dL 80% ≤1.5 g/dL 97% ≤2.0 g/dL 100%</td>
</tr>
<tr>
<td>10 - 11.9 g/dL</td>
<td>≤1.0 g/dL 68% ≤1.5 g/dL 96% ≤2.0 g/dL 99%</td>
</tr>
<tr>
<td>12 - 18 g/dL</td>
<td>≤1.0 g/dL 67% ≤1.5 g/dL 87% ≤2.0 g/dL 94%</td>
</tr>
<tr>
<td>6 – 18 g/dL</td>
<td>≤1.0 g/dL 69% ≤1.5 g/dL 91% ≤2.0 g/dL 97%</td>
</tr>
</tbody>
</table>
Hemocue (g/dL)
CO-ox (g/dL)
tHb (g/dL)
SpHb (g/dL)

> n = 471 samples
> SpHb = 0.0 + 1.0 g/dL,
> HemoCue = 0.3 + 1.3 g/dL
> CO-Oximeter = 0.9 ± 0.6 g/dL

Trend Accuracy – Masimo SpHb

Continuous Non-Invasive Measurement of Hemoglobin via Pulse CO-Oximetry During Liver Transplantation

Trend Accuracy – Masimo SpHb

Correlation (R / R²)

A. SpHb
   0.64 / 0.41
B. CO-Oximeter
   0.6 / 0.36
C. Hemocue
   0.39 / 0.15

Non-Invasive Oxygen Content (SpOC)

- Oxygen demand increases in critically ill patients
  - SpO₂ or Hb alone do not provide oxygen content
  - A patient can have normal SpO₂ or Hb and have low oxygen content

- SpOC Parameter factors both SpO₂ and Hb together
  - Enables combined assessment in quick, automated, and continuous manner
  - Uses accepted formula (CaO₂) with noninvasive instead of invasive parameters

SpOC = SpHb x SpO₂ x 1.31 (ml O₂/g Hb) + 0.3 ml/dL
Weighing the Pros & Cons....
## Six Important Evaluation Areas

<table>
<thead>
<tr>
<th></th>
<th>CBC</th>
<th>CO-ox</th>
<th>POC</th>
<th>Non-Invasive</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pain / Blood Sample Req</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Time to Receive Results</strong></td>
<td>Slow</td>
<td>Slow</td>
<td>Fast</td>
<td>Fast</td>
</tr>
<tr>
<td><strong>Continuous Trending</strong></td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Easy to Perform</strong></td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Measures Abnormal Hgb</strong></td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Accurate</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
If You Told Me 20 Years Ago....
For More Information on Non-Invasive Pulse CO-Oximetry

www.masimo.com

Click on “Clinical Evidence”

All known studies on each parameter
Thank You!

You'd better get out of the sun, looks like you're done.

Tom