BLOOD CONSERVATION AT THE POINT-OF-CARE: USING THE RIGHT TOOLS CAN MAKE A DIFFERENCE

Nam K. Tran, PhD, MS, FACB
Assistant Professor
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Learning Objectives
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• Review the importance of blood conservation and transfusion management with respect to patient care and financial impact.
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• Understand the clinical application of oximetry and how calculated results like oxygen saturation compare.
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• Understand the analytical performance advantages and disadvantages of cyano-hemoglobin-, conductance-, and optical-based methods for the measurement of total hemoglobin.

• Understand the clinical application of oximetry and how calculated results like oxygen saturation compare.

• Learn to apply strategies at the point of care to control the pre-analytical phase and improve the quality of total hemoglobin results.
Clinical Importance and Indications for Transfusions

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- Blood transfusions are clinically indicated when total hemoglobin (tHb) levels fall below a specified threshold.

- Several acute care studies suggest a tHb cutoff of <7 g/dL is safe for transfusion in most populations.\(^2,3,4\)

- Special surgical populations may or may not benefit from higher cutoffs (e.g., cardiovascular and burn patients).\(^5,6\)

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Special Surgical Populations

**Cardiovascular:** Patients with acute coronary syndrome with ischemia may benefit from tHb transfusion cutoffs of 8 to 10 g/dL.\(^1\)

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Burns: Patients with burn injury may not be comparable to “trauma patients”.²

• Massive need for wound healing may increase blood product demand.

• High intraoperative blood loss (~1.5 to 2% of blood volume per percent body surface excised!)

OVERVIEW OF HEMOGLOBINOMETRIC METHODS
Contemporary Hemoglobinometric Techniques

- **Spectrophotometric (Non-Cyanohemoglobin)**

  - Measurement of hemoglobin is based on the absorption spectra
  - Oxy- and deoxyhemoglobin exhibit different absorption in the red to IR wavelengths.
  - Measurement based on Beer’s Law ($A = elc$).
  - Some methods require lysis and reacting with non-cyanide-based reagents.
Contemporary Hemoglobinometric Techniques

• Spectrophotometric (Non-Cyanohemoglobin)

• Non-cyanide based hemoglobin measurements may or may not require chemical modification.

• Certain assays use a modified azide-methemoglobin reaction to measure hemoglobin at 570 nm and 880 nm.
Contemporary Hemoglobinometric Techniques

Spectrophotometric (Cyanohemoglobin)

- Hemoglobin is converted into cyanohemoglobin using a dilute solution of potassium cyanide and potassium ferricyanide.

  \[ \text{Hb and HbCO} \rightarrow \text{methemoglobin} \rightarrow \text{cyanohemoglobin} \]

- Measurement of cyanohemoglobin product is similar to non-cyanohemoglobin methods based on Beer’s Law.

- Hemoglobin S variants may be incorrectly measured using this method.
Contemporary Hemoglobinometric Techniques

Pulse CO-Oximetry (Spectrophotometric): Non-Invasive

Absorption Function

\[ A = \varepsilon LC \]

- \( A \) is absorption
- \( \varepsilon \) is the absorptivity constant
- \( L \) is the path length
- \( C \) is the concentration of absorbing species

Contemporary Hemoglobinometric Techniques

Pulse CO-Oximetry (Spectrophotometric): Non-Invasive

- Suggested to potentially provide real-time trending of hemoglobin values.
- Identify the “vector” or trajectory of hemoglobin levels to anticipate need for transfusions.

Contemporary Hemoglobinometric Techniques

Limitations for Measuring Low Hemoglobin Levels

- Unfortunately, non-invasive hemoglobin measurements are based on *in vitro* data.
Contemporary Hemoglobinometric Techniques

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- Limited data or performance issues at total hemoglobin <10 g/dL forces manufacturers to extrapolate information.
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- Unfortunately, non-invasive hemoglobin measurements are based on *in vitro* data.
- Limited data or performance issues at total hemoglobin <10 g/dL forces manufacturers to extrapolate information.
- Hemoglobin results may not be reliable below 8-10 g/dL.
- Results reliability may also decrease due to hypotension/hypoperfusion similar to pulse oximetry.

Kost GJ, Tran NK. Crit Care Med 2011;39:2369-71
Image recognition by iPad enables quantification of hemoglobin from the blood soaked sponge. Results are transmitted to the cloud for near instantaneous estimation of hemoglobin loss.

Exhibits similar or perhaps greater variability due to methodology. **Clinical efficacy currently not proven.**
Contemporary Hemoglobinometric Techniques

Conductance (Impedance)

Electrode

- Red blood cell membranes are not conductive.

High Resistance VS. Low Resistance
Contemporary Hemoglobinometric Techniques

Conductance (Impedance)

Electrode VS.

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Contemporary Hemoglobinometric Techniques

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- The number of red blood cells is proportional to the change in conductance and conforms to Ohm’s Law ($V = IR$)
Contemporary Hemoglobinometric Techniques

Conductance (Impedance)

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• Red blood cell membranes are not conductive.

• The number of red blood cells is proportional to the change in conductance and conforms to Ohm’s Law ($V = IR$)

• Conductance-based methods measure hematocrit. The hematocrit can then be used to calculate hemoglobin based on a conversion factor (estimated hemoglobin = hematocrit / 3.4)*
Contemporary Hemoglobinimetric Techniques

Conductance (Impedance)

Electrode VS.
CONFOUNDING FACTORS IN HEMOGLOBINOMETRY
Confounding Factors Affecting Hemoglobin Measurement

Pre-Analytical

- Labeling
- Specimen collection/processing errors
- Specimen quality
Confounding Factors Affecting Hemoglobin Measurement

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- Labeling
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• Results reporting delays
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Confounding Factors Affecting Hemoglobin Measurement

Pre-Analytical

• Most common source of errors for laboratory testing

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- Air bubbles
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- Incorrect sample type (arterial vs. venous)
- Mislabling

### Specimen Quality

- Hemodilution
- Contamination
- Interferences
Does it really matter?
Case Study 1: Specimen Collection

Background: Anesthesia reports “impossible venous blood gas values” in one patient where end tidal CO2 was greater than the venous blood gas (VBG).
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- POC Venous Blood Gas: pH = 7.54, pCO2 = 17.5, pO2 = **168.5**
- POC VBG#2: pH = 7.56, pCO2 = 12.7, pO2 = **165.9**
- End tidal CO2 = 28
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Blood Gas Laboratory identified “air bubbles” in syringe
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- Lab Venous Blood Gas: pH 7.54, pCO2 = 19.2, pO2 = **161.5**
- Air bubbles can quickly (<5 mins) cause the specimen to equilibrate atmospheric air (1 atm = 760 mmHg = 0.21 x 760 = 150 mmHg for pO2!!!)
Case Study 2: Specimen Collection

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- Hct = 41%
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RE-MIXING!
- Hct = 43%
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**RE-MIXING!**
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Inadequate mixing may result in artificial changes in total hemoglobin measurements.
Confounding Factors Affecting Hemoglobin Measurement

Pre-Analytical

• Most common source of errors for laboratory testing

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Contemporary Hemoglobinometric Techniques

Conductance (Impedance)

Electrode

High Resistance

• Conversion factor for hematocrit to hemoglobin of 3 may be inappropriate for some special populations.
Contemporary Hemoglobinometric Techniques

**Conductance (Impedence)**

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- The equation, hemoglobin = hematocrit / 3.4 assumes a consistent fraction in grams per deciliter of hemoglobin per percent hematocrit.

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These studies suggest an alternative conversion factor corrected to be used for these populations.

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- Plasma protein content contributes to hematocrit measurements for conductance-based systems.

\[ \text{= Plasma Protein} \]

High Resistance
Contemporary Hemoglobinometric Techniques

Conductance (Impedance) $\bullet = \text{Plasma Protein}$

Electrode

Low Resistance from low plasma protein concentration!

- Plasma protein content contributes to hematocrit measurements for conductance-based systems.

- Conductance-based systems assumes a relatively fixed protein concentration. Therefore, during hemodilution, hematocrit may be falsely lower and causing an underestimation of total hemoglobin.
Contemporary Hemoglobinometric Techniques

**Conductance (Impedance)**

- Plasma protein content contributes to hematocrit measurements for conductance-based systems.
- Conductance-based systems assumes a relatively fixed protein concentration. Therefore, during hemodilution, hematocrit may be falsely lower and causing an underestimation of total hemoglobin.
- **UCDMC Study**: Comparison of a handheld blood gas analyzer using conductance-based measurement of hemoglobin versus a benchtop blood gas analyzer using a spectrophotometric-based method for hemoglobinometry.
Clinical Impact of Hemodilution for Point-of-Care Hemoglobin Measurements

- Sixty patients requiring cardiac surgery were evaluated.
- Paired specimens were tested using a handheld POC analyzer and spectrophotometric methods through the core laboratory.
- Mean (SD) bias was -1.4 (1.1) g/dL, $P = 0.011$.
- Based on core laboratory results 12 patients would have received unnecessary transfusions.
Sixty patients requiring cardiac surgery were evaluated.

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$219 \times 12 = \text{\$2,628 POTENTIALLY WASTED}$

Case Study 3: Analytical Performance

The MAUDE database houses medical device reports submitted to the FDA by mandatory reporters (manufacturers, importers and device user facilities) and voluntary reporters such as health care professionals, patients and consumers.

The FDA receives several hundred thousand medical device reports (MDRs) of suspected device-associated deaths, serious injuries and malfunctions. The FDA uses MDRs to monitor device performance, detect potential device-related safety issues, and contribute to benefit-risk assessments of these products. The MAUDE database houses MDRs submitted to the FDA by mandatory reporters (manufacturers, importers and device user facilities) and voluntary reporters such as health care professionals, patients and consumers.
Case Study 3: Analytical Performance

**Background:** FDA MAUDE database reports a case (03P76-25) of a neonatal patient with discrepant point-of-care (POC) hemoglobin values compared to the laboratory. The POC device used a conductance-based method of hemoglobin measurement, while the laboratory used a spectrophotometric method.
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- POC device reported a hematocrit of 22%. Physician administered 7 mL of blood based on the POC result.
- Transfusion was stopped halfway after the laboratory reported a hematocrit of 40% and hemoglobin of 11.7 g/dL.
- Post-transfusion POC and lab hematocrit values were 45 and 50% respectively.
ANALYTICAL PERFORMANCE OF OPTICAL VERSUS CONDUCTIVE BASED HEMOGLOBIN MEASUREMENTS
Analytical Performance of Optical vs. Conductance-Based Hemoglobinometry
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**Objective:** Compare the analytical performance for total hemoglobin via three point-of-care blood gas analyzers when compared to a central laboratory method.
Analytical Performance of Optical vs. Conductance-Based Hemoglobinometry

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Methods: Enroll 50 adult surgical intensive care unit and operating room patients with hemoglobin of < 8 g/dL. Mean bias compared to the central laboratory method will be determined by one-way analysis variance. Patient chart review conducted to determine if POCT results could have changed patient care. Instruments included:
Analytical Performance of Optical vs. Conductance-Based Hemoglobinometry

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Device#1

Format: Handheld

Hb Method: Conductance

Analysis Time: 30 secs

Sample Volume: 95 microliters
Analytical Performance of Optical vs. Conductance-Based Hemoglobinometry

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Device#1

Device#2

Format: Handheld
Hb Method: Conductance
Analysis Time: 30 secs
Sample Volume: 92 microliters
Analytical Performance of Optical vs. Conductance-Based Hemoglobinometry

Objective: Compare the analytical performance for total hemoglobin via three point-of-care blood gas analyzers when compared to a central laboratory method.

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Device#1

Device#2

Device#3

Format: Portable

Hb Method: Spectrophotometric

Analysis Time: 35 secs

Sample Volume: 65 microliters
Analytical Performance of Optical vs. Conductance-Based Hemoglobinometry

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Device#3

Reference Method
Analytical Performance of Optical vs. Conductance-Based Hemoglobinometry

\[ y = 0.5092x + 4.0176 \]
\[ R^2 = 0.5253 \]
Analytical Performance of Optical vs. Conductance-Based Hemoglobinometry

Device #2 Hb (g/dL) vs. Central Laboratory Hb (g/dL)

- Linear regression equation: $y = 0.5249x + 3.9443$
- Coefficient of determination ($R^2$): 0.5407
Analytical Performance of Optical vs. Conductance-Based Hemoglobinometry

Device #3 Hb (g/dL)

y = 0.9345x + 0.4057
R² = 0.9205
Analytical Performance of Optical vs. Conductance-Based Hemoglobinometry

Notes: *** P<0.001, Lab = Beckman LH hematology analyzer
Analytical Performance of Optical vs. Conductance-Based Hemoglobinometry

Serial Testing Performance at 7 and 8 g/dL
- Serial testing revealed significant analytical bias between spectrophotometry vs. conductance-based measurements.

Notes: *** P<0.001, Central Lab = Spectrophotometric Method, n = 20 patients
Analytical Performance of Optical vs. Conductance-Based Hemoglobinometry

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- All serial conductance measurements were at risk for potential transfusions if the 8 g/dL cutoff was used.

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- Conductance-based devices would have prompted unnecessary transfusions at time point #5 for patients using the 7 g/dL cutoff.
- All serial conductance measurements were at risk for potential transfusions if the 8 g/dL cutoff was used.

Notes: *** P<0.001, Central Lab = Spectrophotometric Method, n = 20 patients
# Manufacturer and User Facility Device Experience (MAUDE) Database Summary

<table>
<thead>
<tr>
<th>Device</th>
<th>Timeframe</th>
<th>Erroneous Results</th>
<th>Improper Transfusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device 1</td>
<td>2011-2016</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Device 2</td>
<td>2011-2016</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Device 3</td>
<td>2014-2016*</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

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• Pre-analytical processing is critical for accurate results. “Junk-in, junk-out”. Institutions should use proper techniques and procedures to ensure good sample quality for accurate hemoglobinometry.
Acknowledgements

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Questions?