Evolution of Blood Gas Analysis - Focusing on the Source of Impaired $O_2$ Supply to the Tissue

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Director of Pathology, Coler-Goldwater Hospital and Nursing Facility
Agenda

Part 1
- Why measure blood gases
- Overview of acid-base disturbances
- Use of the Acid-Base Chart

Part 2 (Today)
- Full value of the $pO_2$ assessment via
  - Oxygen uptake, Oxygen transport, Oxygen release
- Why a measured saturation is the best
- Assessment of tissue perfusion - Lactate
Traditionally, $pO_2(a)$ has been the sole parameter used for evaluation of patient oxygen status.
The traditional picture

- Traditionally, $pO_2(a)$ has been the sole parameter used for evaluation of patient oxygen status.
- For a complete evaluation of the oxygen status, it is necessary to consider lactate and all parameters involved in oxygen uptake, transport, and release.
Example of a flowchart

[Adapted from different textbooks and Siggaard-Andersen, O et al. Oxygen status of arterial and mixed venous blood. Crit Care Med. 1995 Jul;23(7):1284-93.]
Phase one: Oxygen uptake
$pO_2(a)$ – the key parameter

- $pO_2(a)$ is the key parameter for evaluation of oxygen uptake in the lung
- When the $pO_2(a)$ is low, the supply of oxygen to cells might be compromised
Conditions affecting $pO_2(a)$

- The amount of oxygen $FO_2(I)$ available
- The degree of intra- and extrapulmonary shunting $FShunt$
- Hypercapnia, high blood $pCO_2$
- The ambient pressure $p(amp)$
**FO₂(I) – fraction of inspired oxygen**

- Oxygen diffuses from the alveoli into the blood
- The higher the oxygen content of the air, the higher $pO₂(a)$
- Breathing room air equals an $FO₂(I)$ of 21 %
- A patient breathing supplemental oxygen may have a $pO₂(a)$ as high as 400 mmHg (and the oxygen saturation is normal)
Evaluation of PO$_2$ in Adult, Neonatal, and Geriatric Patients Breathing Room Air

<table>
<thead>
<tr>
<th>Arterial PO$_2$ (mmHg)</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>above 80</td>
<td>Normal for adult ($\leq$ 60 y)</td>
</tr>
<tr>
<td>above 70</td>
<td>Adequate for age $&gt;70$ y</td>
</tr>
<tr>
<td>above 60</td>
<td>Adequate for age $&gt;80$ y</td>
</tr>
<tr>
<td>50 to 75</td>
<td>Normal neonatal at 5 min</td>
</tr>
<tr>
<td>60 to 90 days</td>
<td>Normal neonatal at 1-5 days</td>
</tr>
<tr>
<td>40 to 60/70/80 hypoxemia</td>
<td>Moderate to mild</td>
</tr>
<tr>
<td>below 40</td>
<td>Severe hypoxemia</td>
</tr>
</tbody>
</table>
## Evaluating Arterial Oxygenation in Patients Breathing O₂-Enriched Air

<table>
<thead>
<tr>
<th>FI-O₂ (%)</th>
<th>Lowest Acceptable PO₂ (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>150</td>
</tr>
<tr>
<td>40</td>
<td>200</td>
</tr>
<tr>
<td>50</td>
<td>250</td>
</tr>
<tr>
<td>80</td>
<td>400</td>
</tr>
<tr>
<td>100</td>
<td>500</td>
</tr>
</tbody>
</table>

Patients with a lower PO₂ may be assumed to be hypoxic on room air.
Estimated FI-O$_2$ of Air When Breathing 100% Oxygen from Nasal Cannula

Rough estimate:

For each L/min of oxygen flow, add 4% to the estimated FI-O$_2$ of air in the room, usually 21%.

Example: What is the estimated FIO$_2$ of the air being inhaled by a person receiving 2 L/min oxygen from a nasal cannula?
Goals of Oxygen Therapy

- Treat hypoxemia
- Decrease work of breathing
  - Hyperventilation typical response to hypoxemia.
- Decrease myocardial work
  - Increased cardiac output is a mechanism to compensate for hypoxemia.
FShunt is the fraction of venous blood not oxygenated when passing the pulmonary capillaries.

Examples of different types of shunt:

**Intrapulmonary respiratory shunt:**
- Also called ventilation-perfusion disturbance
- Incomplete oxygenation in lung
- Lung diseases with inflammation or edema that causes the membranes to thicken

**Intrapulmonary circulatory shunt:**
- Incomplete oxygenation in lung
- Insufficient blood perfusion of the lungs

**Cardiac shunt:**
- By some called true shunt
- Heart defects allowing venous blood from left chamber of heart to enter right chamber
Shunt is calculated with values from simultaneously drawn arterial and mixed venous samples
- The mixed venous sample must be drawn from the pulmonary artery, as indicated in the illustration

A simpler and faster way to estimate $F_{\text{Shunt}}$ is from a single arterial sample
- Assuming that the arterio-venous difference is normal, i.e. extraction of 5.1 mL O$_2$ per dL blood
**Hypercapnia, high $pCO_2$**

- Strong hypercapnia significantly decreases alveolar $pO_2$, a condition known as hypoventilatory hypoxemia.

- The hypoxemia develops because the alveolar gas equation dictates a fall in $pO_2(a)$:

  $$pO_2(A) = pO_2(\text{air}) - pCO_2(A)/RQ$$

- At any given barometric pressure, any increase in alveolar $pCO_2$ (caused by hypoventilation) leads to a fall in alveolar $pO_2$ and therefore also in arterial $pO_2$. 
Oxygen uptake – a recap

- The amount of oxygen $FO_2(I)$ available
- The degree of intra- and extrapulmonary shunting $F_{Shunt}$
- Hypercapnia, high blood $pCO_2$
- The ambient pressure $p(amp)$
Phase two: Oxygen transport
ctO$_2$ – the key parameter

- Oxygen content, ctO$_2$ is the key parameter for evaluating the capacity for oxygen transport.

- When ctO$_2$ is low, the oxygen delivery to the tissue cells may be compromised.
Does $\text{ctO}_2/\text{pO}_2$ correlate?

- A multicenter study on 10079 blood samples [1]
- $\text{ctO}_2/\text{pO}_2$ correlation unpredictable
- $\text{ctO}_2$ is almost independent of $\text{pO}_2$, so full information is needed
- E.g. $\text{pO}_2$ of 60 mmHg (8 kPa) corresponds to a $\text{ctO}_2$ of 4.8 – 24.2 mL/dL

Oxygen content

- The blood’s oxygen content, ctO₂, is the sum of:
  - Oxygen bound to hemoglobin and
  - Physically dissolved oxygen
- 98% of oxygen is carried by hemoglobin
- The remaining 2% is dissolved in a gas form
- ctO₂ normal range 18.8-22.3 mL/dL

\[
ctO_2 = sO_2 \times ctHb \times (1 - FCOHb - FMetHb) + \alpha O_2 \times pO_2
\]

\(\alpha\) is the solubility coefficient of oxygen in blood
Conditions affecting $ctO_2$

- The concentration of hemoglobin $ctHb$
- The fraction of oxygenated hemoglobin $FO_2Hb$
- The arterial oxygen saturation $sO_2$
- The presence of dyshemoglobins $FCOHb$ and $FMetHb$
Improving $ctO_2$

- The oxygen content can be improved by the variable factors in the equation

$$\text{ctO}_2 = sO_2 \times \text{ctHb} \times (1 - FCOHb - FMetHb) + \alpha O_2 \times pO_2$$

- **blood transfusion**
- **Dyshemoglobins:** can be removed
- **increasing $FIO_2$**
Types of hemoglobin

- **tHb** is defined as the sum of HHb + O₂Hb + COHb + MetHb

- COHb and MetHb are called dyshemoglobins because they are incapable of oxygen transport

<table>
<thead>
<tr>
<th>tHb</th>
<th>Total hemoglobin</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHb</td>
<td>Reduced hemoglobin</td>
</tr>
<tr>
<td>O₂Hb</td>
<td>Oxyhemoglobin</td>
</tr>
<tr>
<td>COHb</td>
<td>Carboxyhemoglobin</td>
</tr>
<tr>
<td>MetHb</td>
<td>Methemoglobin</td>
</tr>
</tbody>
</table>
Hemoglobin

- Hemoglobin consists of 4 identical subunits
- Each subunit contains an iron atom, $\text{Fe}^{2+}$
- Each iron can bind to one oxygen molecule, $\text{O}_2$
- Oxygen binding is cooperative
- Typical reference range is 12-17 g/dL
Carboxyhemoglobin

- Causes of raised COHb:
  - Increased endogeneous production of CO
  - Breathing air polluted with CO (carbon-monooxide poisoining)
- CO’s affinity to Hb is 210 times higher than that of O₂
- The blood turns cherry-red, but is not always evident
- COHb is normally less than 1-2 % but in heavy smokers up to 10 %
Endogeneous increase in COHb

- Hemolytic condition leads to heme catabolism and thus increased production of CO [1]
- Hemolysis induced increase in COHb can be up to 4% but 8.3% is also reported [2]
- Slight increase in COHb is also a feature of a inflammatory disease, and is thus also seen in critically ill patients [3]

COHb intoxication

- COHb intoxication may be deliberate or accidental
- In the US it accounts for 40,000 ED visits and between 5 and 6,000 deaths a year (2004) [1]
- Sources of CO – common [2]
  - Fire, motor-vehicle exhaust and faulty domestic heating systems
  - Less commonly, gas ovens, paraffin (kerosene) heaters and even charcoal briquettes

# Relationship COHb

<table>
<thead>
<tr>
<th>CO conc. in inspired air (ppm)</th>
<th>COHb in blood %</th>
<th>Examples of typical symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>10</td>
<td>No appreciable effect except shortness of breath on vigorous exertion, possible tightness across forehead</td>
</tr>
<tr>
<td>120</td>
<td>20</td>
<td>Shortness of breath on moderate exertion, occasional headache</td>
</tr>
<tr>
<td>220</td>
<td>30</td>
<td>Headache, easily fatigued, judgement disturbed, dizziness, dimness of vision</td>
</tr>
<tr>
<td>350-520</td>
<td>40-50</td>
<td>Headache, confusion, fainting, collapse</td>
</tr>
<tr>
<td>800-1200</td>
<td>60-70</td>
<td>Unconsciousness, convulsions, respiratory failure, death if exposure continues</td>
</tr>
<tr>
<td>1950</td>
<td>80</td>
<td>Immediately fatal</td>
</tr>
</tbody>
</table>

Clinical cases - Carboxyhemoglobin

Read three interesting case stories in “Causes and clinical significance of increased carboxyhemoglobin” by Chris Higgins on www.acutecaretesting.org
Methemoglobin

- Methemoglobin is formed when blood is exposed to oxidizing agents, oxidizing the iron atom: $\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}$
- MetHb has a very low affinity to $\text{O}_2$
- The blood typically turns dark brown
Causes for increased methemoglobin

- Inherited – very seldom
- Acquired – more frequent
- Acquired methemoglobinemia occurs when hemoglobin is oxidized in a rate faster by which methemoglobin is reduced
- Drugs or toxins that may cause methemoglobinemia
  - Acetanilide, p-aminosalicylic acid, amyl nitrate, aniline, benzocaine, cetacaine, chloroquinone, clorfazimine, dapsone, hydroxylamine, isobutyl nitrite, lidocaine, mafenide acetate, menadione, metoclopramide, naphthoquinone, nitric oxide, nitrobezene, nitroethane, nitrofurane, nitroglycerin, nitroprusside, paraquat, phenacitin, phenazopyridine, prilocaine, primaquine, resorcinol, silver nitrate, sodium nitrate, sodium nitrite, sodium valproate, sulphonamide antibiotics, trinitrotoluene

### Effect of MetHb

<table>
<thead>
<tr>
<th>MetHb in blood %</th>
<th>Examples of typical symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-10</td>
<td>Is typically well tolerated and, in an otherwise healthy individual, is asymptomatic</td>
</tr>
<tr>
<td>10-15</td>
<td>Typically first sign of tissue hypoxia is cyanosis with skin taking on a classically blue/slate gray appearance. Symptoms: more profound hypoxia, including increased heart rate, headache, dizziness and anxiety, accompany deepening cyanosis as methemoglobin rises above 20 %.</td>
</tr>
<tr>
<td>&gt;50</td>
<td>May be associated with increasing breathlessness and fatigue. Confusion, drowsiness and coma Methemoglobin</td>
</tr>
<tr>
<td>&gt;70</td>
<td>May be fatal</td>
</tr>
</tbody>
</table>

Symptoms of methemoglobinemia are generally more severe in a patient who has some pre-existing condition (e.g. anemia, respiratory or cardiovascular disease) that compromises oxygenation of tissues.

Clinical cases - Methemoglobin

Read three interesting case stories in “Methemoglobin” by Chris Higgins on www.acutecaretesting.org
Case

- A 84-year-old man had undergone a left hemicolecotomy for bowel torsion. After 10 days he became hypotensive, tachypneic, oliguric, progressively acidotic, and anemic. Also, the patient had passed bloody stools
- \( \text{ctO}_2 \) normal range: 18.8-22.3 mL/dL

<table>
<thead>
<tr>
<th>1) With a ( FO_2(I) ) of 0.6 a blood sample showed</th>
<th>2) After bicarbonate and blood had been administered i.v.</th>
</tr>
</thead>
<tbody>
<tr>
<td>- ( \text{pH} = 7.25 )</td>
<td>- ( \text{pH} = 7.35 )</td>
</tr>
<tr>
<td>- ( p\text{CO}_2 = 29 \text{ mmHg} )</td>
<td>- ( p\text{CO}_2 = 24 \text{ mmHg} )</td>
</tr>
<tr>
<td>- ( p\text{O}_2 = 169 \text{ mmHg} )</td>
<td>- ( p\text{O}_2 = 169 \text{ mmHg} )</td>
</tr>
<tr>
<td>- ( \text{ctHb} = 4.2 \text{ g/dL} )</td>
<td>- ( \text{ctHb} = 7.8 \text{ g/dL} )</td>
</tr>
<tr>
<td>- ( s\text{O}_2 = 98 % )</td>
<td>- ( s\text{O}_2 = 98 % )</td>
</tr>
<tr>
<td>- ( \text{ctO}_2 = 6.08 \text{ mL/dL} )</td>
<td>- ( \text{ctO}_2 = 10.8 \text{ mL/dL} )</td>
</tr>
</tbody>
</table>
Oxygen transport – a recap

- The concentration of hemoglobin $ctHb$
- The fraction of oxygenated hemoglobin $FO_2Hb$
- The arterial oxygen saturation $sO_2$
- The presence of dyshemoglobins $FCOHB$ and $FMetHb$
Phase three: Oxygen release
Conditions affecting release

- Oxygen release depends primarily on:
  - The arterial and end-capillary oxygen tensions and \(ctO_2\)
  - The hemoglobin-oxygen affinity expressed by the \(p50\) value
  - \(p50\) is the key parameter for evaluation of oxygen release from hemoglobin
Conditions affecting $p50$

- The hemoglobin-oxygen affinity is expressed by the oxygen dissociation curve (ODC), the position of which is expressed by the $p50$ value.
- As illustrated in the flowchart, several conditions can affect the $p50$ value:
  - Metabolic alkalosis
  - Respiratory alkalosis
  - Hyperventilation
  - Hypophosphatemia
  - Smoke or gas poisoning
  - Neonates, hematological disorders

\[\begin{align*}
\text{Oxygen release} & \quad \text{Metabolic alkalosis} \\
\text{pH} & \quad \text{Respiratory alkalosis} \\
\rho CO_2 & \quad \text{Hyperventilation} \\
\text{Temp} & \quad \text{Hypophosphatemia} \\
c2,3-DPG & \quad \text{Smoke or gas poisoning} \\
F COHb & \quad \text{Neonates, hematological disorders} \\
F HbF & \quad \text{decreasing value} \\
\end{align*}\]
p50 and the ODC curve

The p50 is the oxygen tension at half saturation (sO₂ = 50 %) and reflects the affinity of hemoglobin for oxygen.

Different factors affect the position of the ODC, and p50 express the position of the curve.

Typical reference range: 25-29 mmHg.
Conditions affecting position of ODC
Can $p_{50}$ be read from the ODC curve? [1]

If $sO_2 = 90\%$ then $pO_2 = 29\text{–}137\text{ mmHg} (4\text{–}18\text{ kPa})$

If $pO_2 = 60\text{ mmHg} (8\text{ kPa})$ then $sO_2 = 70\text{–}99\%$

Conclusion: Need information about $p_{50}$ via measurement of the factors affecting ODC (MetHb, COHb etc)

Oxygen release – a recap

- The hemoglobin-oxygen affinity is expressed by the oxygen dissociation curve (ODC), the position of which is expressed by the \( p50 \) value.
- As illustrated in the flowchart, several conditions can affect the \( p50 \) value.

![Flowchart showing factors affecting the \( p50 \) value](image_url)
Some cases using the Flowchart
Case

- 75-year-old woman
- Suffering from anemia, probably due to an ulcer
- What to do?
- Some of the results from the lab showed

- $\text{pH} = 7.40$ (7.35-7.45)
- $\text{pCO}_2 = 40 \text{ mmHg}$ (35-48)
- $\text{pO}_2 = 98 \text{ mmHg}$ (83-108)
- $\text{FO}_2(I) = 0.21$
- $\text{ctHb} = 9.0 \text{ g/dL}$ (12.0-17.5)
- $\text{ctO}_2 = 8.8 \text{ mg/dL}$ (18.8-22.3)
- $\text{sO}_2 = 97 \%$ (95-99)
- $\text{FMetHb} = 0.005$ (.002-.008)
- $\text{FCOHb} = 0.005$ (0.0 – 0.008)
- $\text{Temp} = 37 \, ^\circ\text{C}$
- $\text{p50} = 25.5 \text{ mmHg}$ (24-28)

This case is not a real life case – it is made for illustration purposes only
Case

This case is not a real life case – it is made for illustration purposes only.

- $pO_2$ 98 mmHg
- $ctO_2$ 8.8 mg/dL
- $p50$ 25.5 mmHg
- $ctHb$ 9.0 g/dL
- No DysHb
- True anemia
40-year-old man
Exposed to smoke from a fire
Some of the test results showed

$$\begin{align*}
\text{pH} &= 7.400 \ (7.35-7.45) \\
\text{pCO}_2 &= 40 \ \text{mmHg} \ (35-48) \\
\text{pO}_2 &= 98 \ \text{mmHg} \ (83-108) \\
\text{FO}_2(I) &= 0.21 \\
\text{ctHb} &= 14.5 \ \text{g/dL} \ (12.0-17.5) \\
\text{ctO}_2 &= 16.6 \ \text{mL/dL} \ (18.8-22.2) \\
\text{sO}_2 &= 97 \ % \ (95-99) \\
\text{FMetHb} &= 0.005 \ (0.002-0.008) \\
\text{FCOHb} &= 0.300 \ (0.0-0.008) \\
\text{Temp} &= 37 \ ^\circ\text{C} \\
\text{p}50 &= 26.3 \ \text{mmHg} \ (24-28)
\end{align*}$$

This case is not a real life case – it is made for illustration purposes only
This case is not a real life case – it is made for illustration purposes only.

- $pO_2$ 98 mmHg
- $ctO_2$ 16.6 mg/dL
- $p50$ 26.3 mmHg
- $ctHb$ 14.5 g/dL
- COHb 30%

CO poisoning
Case

- 15-year-old boy
- Severe asthmatic attack
- Some of the test results showed

\[
\begin{align*}
\text{pH} &= 7.350 \ (7.35-7.45) \\
\text{pCO}_2 &= 35 \text{ mmHg} \ (35-48) \\
\text{pO}_2 &= 60 \text{ mmHg} \ (83-108) \\
\text{F} \text{O}_2(\text{l}) &= 0.21 \\
\text{ctHb} &= 14.5 \text{ g/dL} \ (12.0-17.5) \\
\text{ctO}_2 &= 15.8 \text{ mL/dL} \ (18.8-22.3) \\
\text{sO}_2 &= 80 \% \ (95-99) \\
F\text{MetHb} &= 0.005 \ (0.002-0.008) \\
F\text{COHb} &= 0.005 \ (0.0-0.008) \\
\text{Temp} &= 37 \degree \text{C} \\
\text{p50} &= 37 \text{ mmHg} \ (24-28)
\end{align*}
\]

This case is not a real life case – it is made for illustration purposes only
Case

This case is not a real life case – it is made for illustration purposes only

$pO_2$ 60 mmHg
$ctO_2$ 15.8 mg/dL
$p50$ 37 mmHg

$pCO_2$ 35 mmHg

Asthma
Oxygen saturation, $sO_2$

$$sO_2 = \frac{cO_2Hb}{cO_2Hb + cHHb} \times 100\%$$

- $sO_2$ is defined as
  - The percentage of oxygenated hemoglobin in relation to the amount of hemoglobin capable of carrying oxygen
- Typical reference interval 95-99 %
  - High $sO_2$:
    - Indicates that there is sufficient utilization of actual oxygen transport capacity
  - Low $sO_2$:
    - Indicates that the patient can likely benefit from supplemental oxygen
- No information about tHb, COHb, MetHb, ventilation or $O_2$-release to tissue
3 different ways to get $sO_2$

1. BG analyzer **with** CO-OX:
   - Measured by the CO-oximeter
   - Golden standard

2. BG analyzer **without** CO-OX:
   - Calculated from a $pO_2(a)$ via the ODC curve

3. Pulse oximeters

$$sO_2 = \frac{cO_2Hb}{cO_2Hb + cHHb} \times 100\%$$
BGA without CO-OX

- **CALCULATED \( sO_2 \)** depends on
  - Available information (parameters)
  - Algorithm applied by manufacturer
Correlation of $pO_2$ and $sO_2$ in real life [1]

- If $sO_2 = 90\%$ then $pO_2 = 29-137$ mmHg (4 – 18 kPa)
- If $pO_2 = 60$ mmHg (8 kPa) then $sO_2 = 70-99\%$
- At $pO_2 = 45$ mmHg (6 kPa) and
  - pH = 7.25, then $sO_2 = 80\%$
  - pH = 7.40, then $sO_2 = 88\%$

Why measured over calculated $sO_2$

Several studies are supporting the importance of using a measured $sO_2$ and not calculated

- CLSI [1]: “Clinically significant errors can result from incorporation of such an estimated value for $sO_2$ in further calculations such as shunt fraction”

- Breuer [2]: “No calculation mode can be performed with constant accuracy and reliability when covering a wide range of acid-base values. If $sO_2$ values are used for further calculations, e.g. for determination of cardiac output, measured values are preferred”

---

A reliable $sO_2$ (and $pO_2$) matters

<table>
<thead>
<tr>
<th></th>
<th>$pO_2(a)$</th>
<th>$sO_2(a)$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hypoxemia - severe</strong></td>
<td>6.0 kPa/45 mmHg</td>
<td>~80 %</td>
</tr>
<tr>
<td><strong>Hypoxemia – moderate</strong></td>
<td>8.0 kPa/60 mmHg</td>
<td>~91 %</td>
</tr>
<tr>
<td><strong>Hypoxemia - mild</strong></td>
<td>9.3 kPa/70 mmHg</td>
<td>~94 %</td>
</tr>
<tr>
<td><strong>Normoxemia</strong></td>
<td>10.6 kPa/80 mmHg</td>
<td>~96 %</td>
</tr>
<tr>
<td><strong>Normoxemia</strong></td>
<td>13.3 kPa/100 mmHg</td>
<td>~98 %</td>
</tr>
<tr>
<td><strong>Hyperoxemia</strong></td>
<td>16.0 kPa/120 mmHg</td>
<td>~98 %</td>
</tr>
<tr>
<td><strong>Hyperoxemia - marked</strong></td>
<td>20.0 kPa/150 mmHg</td>
<td>~99-100 %</td>
</tr>
</tbody>
</table>
Pulse oximetry

- SpO$_2$
- Reflects the utilization of the current oxygen transport capacity
- Continuous monitoring
- Noninvasive method
- Easy and convenient
- 37 out of 42 pulse oximeters companies reported best analytical performance as 1SD of +/- 2% [1, 2]

[1] From www.fda.gov as accessed September 2010,
Pulse oximeters in the ICU

Reputation: 90’ies studies conclude like these:

- "We conclude that the accuracy of the tested nine pulse oximeters does not enable precise absolute measurements, specially at lower oxygen saturation ranges” [1]
- "Infants with acute cardiorespiratory problems, pulse oximetry unreliably reflects \( pO_2(a) \), but may be useful in detecting clinical deterioration [2]

A 2010 publication [3]

- “The accuracy of pulse oximetry to estimate arterial oxygen saturation in critically ill patients has yielded mixed results. Both the degree of inaccuracy, or bias, and its direction has been inconsistent”…“analysis demonstrated that hypoxemia (\( sO2(a) < 90 \)) significantly affected pulse oximeter accuracy. The mean difference was 4.9 % in hypoxemic patients and 1.89 % in non-hypoxemic patients (\( p < 0.004 \)). In 50 % (11/22) of cases in which \( SpO2 \) was in the 90-93 % range the \( sO2(a) \) was <90 % ”.

A 2012 publication [4]

- “Despite its accepted utility, it is not a substitute for arterial blood gas monitoring as it provides no information about the ventilatory status and has several other limitations”.

Oxygen saturation - Summary

- **GOLDEN STANDARD** is the oxygen saturation measured by the CO-oximeter analysis.

- Other oxygen saturation methods have various limitations.

- Oxygen saturation does not give information on oxygen delivery, ventilation, etc.
Does the oxygen get to the tissue?

- Lactate is a waste product from anaerobic metabolism
  - Takes place when there is insufficient oxygen delivery to tissue cells
  - Thus lactate is an early sensitive indicator imbalance between tissue oxygen demand and oxygen supply
Lactate is used....

- ......as a tool for
  - Diagnostically, admitting and triaging patients
  - As a marker of tissue hypoperfusion in patients with circulatory shock
  - As an index of adequacy of resuscitation after shock
  - As a marker for monitoring resuscitation therapies
  - Prognostically, as a prognostic indicator for patient outcome.

From: Bakker J. Increased blood lactate levels: a marker of...? www.acutecaretesting.org Jun 2003
When to measure lactate?

- When there are signs and symptoms such as:
  - Rapid breathing, nausea, hypotension, hypovolemia and sweating that suggest the possibility of reduced tissue oxygenation or an acid/base imbalance
  - Suspicion of inherited metabolic or mitochondrial disorder.
Data shows that…..

- **Lactic acidosis**
  - Occurs in approximately 1% of hospital admissions[1].
  - Has a mortality rate greater than 60% and approaches 100% if hypotension also is present [1].

- **Elevated lactate**
  - Have been demonstrated to be associated with mortality in both emergency departments and hospitalized patients [2, 3, 4, 5].

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The surviving sepsis campaign care bundle recommends, among others, to measure lactate within 3 hours of admission.

If lactate is elevated a second lactate measure could be completed within 6 hours [1].

Hyperlactatemia and lactic acidosis

- **Hyperlactatemia:**
  - Is typically defined as a lactate >2.0 mmol/L
  - Occurs when the rate of lactate release from peripheral tissue exceeds the rate of lactate removal by liver and kidneys

- **Lactic acidosis**
  - If lactate is > 3-4mmol/L there is increasing risk of associated acidosis
  - The combination of hyperlactatemia and acidosis is called lactic acidosis, which is a disruption of acid/base balance.
Lactic acidosis A and B

- **Type A (hypoxic)**
  - Inadequate oxygen uptake in the lungs and/or to reduced blood flow resulting in decreased transport of oxygen
  - E.g.: Shock from blood loss/sepsis, myocardial, infarction/cardiac arrest, congestive heart failure, pulmonary edema, severe anemia, severe hypoxemia, carbon monoxide poisoning

- **Type B (metabolic)**
  - Conditions that increase the amount of lactate in the blood but are not related to a decreased availability of oxygen
  - E.g.: Liver disease, Kidney disease, Diabetic ketoacidosis (DKA), Leukemia, HIV, glycogen storage diseases (like glucose-6-phosphatase deficiency), server infections – both systemic sepsis and meningitis, strenuous exercise
  - Drugs and toxins typically represent the most common cause of type B lactic acidosis
Lactic acidosis and pH

- No universal agreement for definition of lactic acidosis [1]
- Lactic acidosis is the most common cause of metabolic acidosis [2].
- Lactic acidosis may not necessarily produce acidemia in a patient as it depends on [1]
  - Magnitude of hyperlactatemia
  - Buffering capacity of the body
  - Coexistence of other conditions that produce tachypnea and alkalosis (eg, liver disease, sepsis).
- Thus, hyperlactatemia or lactic acidosis may be associated with acidemia, a normal pH, or alkalemia [1]

Lactate and oxygen uptake, transport and release [1]

<table>
<thead>
<tr>
<th>ABG test</th>
<th>Units</th>
<th>Examples of reference interval</th>
<th>Short summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>pH</td>
<td>7.35–7.45</td>
<td>Indicates the acidity or alkalinity of blood. pH is the indispensable measure of acidemia or alkalemia.</td>
</tr>
<tr>
<td>pCO₂(a)</td>
<td>mmHg (kPa)</td>
<td>M 35–48 (4.7-6.4) F 32–45 (4.3–6.0)</td>
<td>pCO₂ is the carbon dioxide partial pressure in blood. pCO₂(a) is a reflection of the adequacy of alveolar ventilation in relation to the metabolic state.</td>
</tr>
<tr>
<td>Bicarbonate (HCO³⁻)</td>
<td>mmol/L</td>
<td>M 22.2-28.3 F 21.2-28.3</td>
<td>Standard HCO³⁻ is standardized with the aim to eliminate effects of the respiratory component on the HCO³⁻. HCO³⁻ is classified as the metabolic component of acid-base balance.</td>
</tr>
<tr>
<td>Base excess (BE)</td>
<td>mmol/L</td>
<td>M -3.2-1.8 F -2.3-2.7</td>
<td>BE predicts the quantity of acid or alkali to return the plasma in vivo to a normal pH under standard conditions. BE may help determine whether an acid/base disturbance is a respiratory, metabolic for mixed metabolic/respiratory problem. Base(Ecf) is independent from changes on pCO₂ and is also called “in-vivo base excess” or “standard base excess” (SBE).</td>
</tr>
<tr>
<td>pO₂(a)</td>
<td>mmHg (kPa)</td>
<td>83-108 (11.1-14.4)</td>
<td>pO₂ is the oxygen partial pressure in blood. The pO₂(a) is an indicator of the oxygen uptake in the lungs.</td>
</tr>
<tr>
<td>sO₂(a)</td>
<td>%</td>
<td>95-99</td>
<td>sO₂(a) is the percentage of oxygenated hemoglobin in relation to the amount of hemoglobin capable of carrying oxygen and indicates if there is sufficient utilization of actual oxygen transport capacity.</td>
</tr>
<tr>
<td>Hemoglobin (Hb)</td>
<td>g/dL (mmol/L)</td>
<td>M 13.5-17.5 F 12.0-16.0 (7.4–9.9)</td>
<td>thB is defined as the sum of HHb+O₂Hb+COHb+MetHb. thB is a measure of the potential oxygen-carrying capacity.</td>
</tr>
<tr>
<td>ctO₂</td>
<td>mmol/L</td>
<td>M 23.3-29.7 F 22.3-28.4</td>
<td>ctO₂ is the blood’s oxygen content and is the sum of oxygen bound to hemoglobin and physically dissolved oxygen. ctO₂ reflects the integrated effects of changes in the arterial pO₂, the effective hemoglobin concentration and the hemoglobin affinity.</td>
</tr>
<tr>
<td>p50</td>
<td>mmHg (kPa)</td>
<td>24–29 (3.2-3.9)</td>
<td>p50 is the oxygen tension at half saturation and reflects the affinity of hemoglobin for oxygen.</td>
</tr>
<tr>
<td>MetHb</td>
<td>%</td>
<td>0–1.5</td>
<td>MetHb is formed when blood is exposed to certain oxidizing agents. MetHb has a very low affinity to O₂ resulting in decreased oxygen-carrying capacity.</td>
</tr>
<tr>
<td>COHb</td>
<td>%</td>
<td>0.5-1.5</td>
<td>COHb is primarily formed when breathing air polluted with CO. COHb is not capable of transporting oxygen.</td>
</tr>
<tr>
<td>Lactate</td>
<td>mg/dl (mmol/L)</td>
<td>4.5–14.4 (0.5-1.6)</td>
<td>Lactate is a waste product from anaerobic metabolism. Lactate is an early sensitive indicator imbalance between tissue oxygen demand and oxygen supply.</td>
</tr>
</tbody>
</table>
Read more

- Sources for Scientific knowledge about acute care testing

**acutecaretesting.org**
Your knowledge site

Blood gas app
- for smartphones and tablets

Avoid preanalytical errors app
- for smartphones