## Normal Blood Gas Value Ranges

<table>
<thead>
<tr>
<th>Blood Gas Value</th>
<th>Arterial</th>
<th>Venous</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.35-7.4</td>
<td>7.30-7.40</td>
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<tr>
<td>PCO₂</td>
<td>35-45 mm Hg</td>
<td>42-48 mmHg</td>
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<tr>
<td>HCO₃</td>
<td>22-28 mEq/L</td>
<td>24-30 mEq/L</td>
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<tr>
<td>PO₂</td>
<td>80-100 mmHg</td>
<td>35-45 mm Hg</td>
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OXYGEN TRANSPORT
Oxygen Dissolved in the Blood Plasma

• Dissolve means that the gas maintains its precise molecular structure
• About .003 mL of \( O_2 \) will dissolve in 100 mL of blood for every 1 mm Hg of \( PO_2 \)
• Thus, a \( PaO_2 \) of 100 = 0.3 mL

\[
100 \times 0.003 = 0.3 \text{ mL}
\]
Oxygen Dissolved in the Blood Plasma

• Written as 0.3 volumes percent (Vol%)
• Vol% represents amount of O$_2$ (in mL) that is in 100 mL of blood

\[ \text{Vol\%} = \frac{\text{mL O}_2}{100 \text{ mL bd}} \]
Oxygen Dissolved in the Blood Plasma

• For example:
  – 10 vol% of $\text{O}_2$ means that there are 10 mL of $\text{O}_2$ in 100 mL of blood
  – Relatively small percentage of oxygen is transported in the form of dissolved oxygen
Oxygen Bound to Hemoglobin

- Each RBC contains about 280 million hemoglobin (Hb) molecules
- Normal adult Hb (Hb A) consists of:
  - 4 heme groups (iron portion of the Hb)
  - 4 amino acid chains: 2 alpha and 2 beta
Hemoglobin Molecule

Fig. 6-1. Schematic illustration of a hemoglobin molecule.

Beta (β) chains

Alpha (α) chains
Oxygen Bound to Hemoglobin

\[ \text{Hb} \quad + \quad \text{O}_2 \quad \xrightarrow{\text{Reduction}} \quad \text{HbO}_2 \]

Reduced hemoglobin (unchanged or deoxygenated hemoglobin)

Oxygen

Oxyhemoglobin (combined or oxygenated hemoglobin)
Oxygen Bound to Hemoglobin

• **Oxyhemoglobin**
  – Hemoglobin bound with oxygen

• **Reduced hemoglobin or deoxyhemoglobin**
  – Hemoglobin not bound with oxygen
Oxygen Bound to Hemoglobin

• Normal adult male Hb value:
  – 14-16 g/100 mL

• Normal adult female Hb value:
  – 12-15 g/100 mL
Oxygen Bound to Hemoglobin

- Clinically, the weight measurement of hemoglobin, in reference to 100 mL of blood, is referred to as either:
  - Gram percent of hemoglobin (g% Hb), or
  - Grams per deciliter (g/dL)
• Each g% Hb can carry 1.34 mL of oxygen
• Thus, if Hb level is 15 g%, and if Hb is fully saturated, about 20.1 vol% of O$_2$ will be bound to the Hb

O$_2$ bound to Hb = 1.34 mL O$_2$ x 15 g% Hb

= 20.1 vol% O$_2$
Quantity of Oxygen Bound to Hemoglobin

• At a normal PaO$_2$ of 100 mm Hg, however, the Hb saturation (SaO$_2$) is only about 97% due to the following three normal physiologic shunts
Quantity of Oxygen Bound to Hemoglobin

- Thebesian venous drainage into the left atrium
- Bronchial venous drainage into pulmonary veins
- Alveoli that are under ventilated—dead space ventilation
Thus, the amount of arterial oxygen in the preceding equation must be adjusted to 97 percent:

\[
\begin{align*}
20.1 \text{ vol}\% \, \text{O}_2 \\
\times 0.97 \\
\frac{}{19.5 \text{ vol}\% \, \text{O}_2}
\end{align*}
\]
Total Oxygen Content

• To determine the total amount of oxygen in 100 mL of blood, the following must be added together:
  – Dissolved oxygen
  – Oxygen bound to hemoglobin
The following case study summarizes the calculations required to compute an individual’s total oxygen content.
Case Study—Anemic Patient

• 27-year-old woman
  – Long history of anemia (decreased hemoglobin concentration)
  – Showing signs of respiratory distress
  – Respiratory rate 36 breaths/min
  – Heart rate 130 beats/min
  – Blood pressure 155/90 mm Hg
Case Study—Anemic Patient

- Hemoglobin concentration is 6 g%
- PaO$_2$ is 80 mm Hg (SaO$_2$ 90%)
Based on this information, the patient’s total oxygen content is computed as follows:

1. Dissolved $O_2$:

\[
\begin{align*}
80 \text{ PaO}_2 \\
\times 0.003 \text{ (dissolved O}_2\text{ factor)}
\end{align*}
\]

0.24 vol% $O_2$
2. Oxygen Bound to Hemoglobin:

\[ 6 \text{ g\% Hb} \times 1.34 \text{ (O}_2\text{ bound to Hb factor)} \]

\[ 8.04 \text{ vol\% O}_2 \text{ (at SaO}_2\text{ of 100\%)} \]

\[ 8.04 \text{ vol\% O}_2 \times 0.90 \text{ SaO}_2 \]

\[ 7.236 \text{ vol\% O}_2 \]
3. Total oxygen content:

\[ 7.236 \text{ vol\% } O_2 \text{ (bound to hemoglobin)} \]

\[ + 0.24 \text{ vol\% } O_2 \text{ (dissolved } O_2) \]

\[ 7.476 \text{ vol\% } O_2 \text{ (total amount of } O_2/100 \text{ ml of blood)} \]
Case Study—Anemic Patient

• Note:
  – Patient’s total arterial oxygen content is less than 50 percent of normal
  – Her hemoglobin concentration, which is the primary mechanism for transporting oxygen, is very low
  – Once problem is corrected, respiratory distress should no longer be present
Total Oxygen Content

• Calculated for following:
  – Arterial Oxygen Content (CaO$_2$)
  – Mixed Venous Oxygen Content (CvO$_2$)
  – Oxygen Content of Pulmonary Capillary Blood (CcO$_2$)
Total Oxygen Content of Arterial Blood

- $\text{CaO}_2 = \text{Oxygen content of arterial blood}$
  
  $(\text{Hb} \times 1.34 \times \text{SaO}_2) + (\text{PaO}_2 \times 0.003)$
Total Oxygen Content of Mixed Venous Blood

- \( \text{CvO}_2 = \text{Oxygen content of mixed venous blood} \)

\[
(Hb \times 1.34 \times \text{SvO}_2) + (\text{PvO} \times 0.003)
\]
Total Oxygen Content of Pulmonary Capillary Blood

• $\text{CcO}_2 = \text{Oxygen content of pulmonary capillary blood}$

\[(\text{Hb} \times 1.34) + (\text{PAO}_2 \times 0.003)\]
Total Oxygen Content

• It will be shown later how various mathematical manipulations of the \( \text{CaO}_2 \), \( \text{CvO}_2 \), and \( \text{CcO}_2 \) values are used in different oxygen transport studies to reflect important factors concerning the patient’s cardiac and ventilatory status.
OXYGEN DISSOCIATION CURVE
Fig. 6-2. Oxygen dissociation curve.
• PO$_2$ can fall from 60 to 100 mm Hg and the hemoglobin will still be 90 percent saturated with oxygen
  – Excellent safety zone
Clinical Significance of the Flat Portion of the Curve

• As the Hb moves through the A-C system, a significant partial pressure difference continues to exist between the alveolar gas and blood, even after most O₂ has transferred
  – This enhances the diffusion of O₂
Clinical Significance of the Flat Portion of the Curve

• Increasing PO$_2$ beyond 100 mm Hg adds very little O$_2$ to the blood
  – Dissolved O$_2$ only
  – (PO$_2$ x 0.003 = dissolved O$_2$)
Clinical Significance of the Flat Portion of the Curve

• A reduction of $PO_2$ below 60 mm Hg causes a rapid decrease in amount of $O_2$ bound to hemoglobin
• However, diffusion of oxygen from hemoglobin to tissue cells is enhanced
• $P_{50}$ represents the partial pressure at which the hemoglobin is 50 percent saturated with oxygen

• Normally, $P_{50}$ is about 27 mm Hg
The $P_{50}$ represents the partial pressure at which hemoglobin is 50 percent saturated with oxygen.
Factors that Shift Oxygen Dissociation Curve

- pH
- Temperature
- Carbon Dioxide
- 2,3-DPG
- Fetal Hemoglobin
- Carbon Monoxide Hemoglobin
Fig. 6-4. Factors that shift the oxygen dissociation curve to the right and left.
CLINICAL SIGNIFICANCE
OF SHIFTS IN THE O$_2$
DISSOCIATION CURVE
• When an individual’s blood PaO$_2$ is within normal limits (80-100 mm Hg):
  – Shift of oxygen dissociation curve to the right or left does not significantly affect hemoglobin’s ability to transport oxygen to the peripheral tissues.
The O\textsubscript{2} Dissociation Curve

• However, when an individual’s blood PaO\textsubscript{2} falls below the normal range:
  – A shift to the right or left can have a remarkable effect on the hemoglobin’s ability to pick up and release oxygen.
  – This is because shifts below the normal range occur on the steep portion of the curve.
The O₂ Dissociation Curve

• For example, consider the loading and unloading of oxygen during the following clinical conditions:
Right Shifts: Loading of Oxygen in Lungs

• Picture the loading of oxygen onto hemoglobin as blood passes through the alveolar-capillary system at a time when the alveolar oxygen tension (PaO$_2$) is moderately low, around 60 mm Hg.
Fig. 6-5. Normally, when the \( \text{PaO}_2 \) is 60 mm Hg, the plasma \( \text{PO}_2 \) is about 60 mm Hg, and Hb is about 90% saturated.
If, however, the oxygen dissociation curve shifts to the right, as indicated in Figure 6-6, the hemoglobin will be only about 75 percent saturated with oxygen as it leaves the alveoli.
Fig. 6-6. When the PAO$_2$ is 60 mm Hg at a time when the curve has shifted to the right because of a pH of 7.1.
Right Shifts: Loading of Oxygen in Lungs

• In view of this gas transport phenomenon, it should be stressed that:
  – Total oxygen delivery may be much lower than indicated by a particular \( \text{PaO}_2 \) value when a disease process is present that causes the oxygen dissociation curve to shift to the right.
Right Shifts: Loading of Oxygen in Lungs

• Although total oxygen delivery may be decreased in the above situation:
  – Plasma PO$_2$ at the tissue sites does not have to fall as much to unload oxygen
• For example, if tissue cells metabolize 5 vol% oxygen at a time when the oxygen dissociation is in the normal position:
  – Plasma PO$_2$ must fall from 60 mm Hg to about 35 mm Hg to free 5 vol% oxygen from the hemoglobin
  – See Figure 6-7
Right Shifts: Unloading of Oxygen at the Tissues

Fig. 6-7. Normally, when the plasma PO$_2$ is 60 mm Hg, the PO$_2$ must fall to about 35 mm Hg to free 5 vol% oxygen for metabolism.
Right Shifts: Unloading of Oxygen at the Tissues

• If, however, the curve shifts to the right in response to a pH of 7.1:
  – Plasma PO$_2$ at tissue sites would only have to fall from 60 mm Hg to about 40 mm Hg to unload 5 vol% oxygen from the hemoglobin
  – See Figure 6-8
Right Shifts: Unloading of Oxygen at the Tissues

Fig. 6-8. When the plasma $PO_2$ is 60 mm Hg at a time when the curve is to the right because of pH of 7.1, the $PO_2$ must fall to about 40 mm Hg to free 5 vol% oxygen for metabolism.
• If the oxygen dissociation curve shifts to left when the $\text{PAO}_2$ is 60 mm Hg at a time when the curve has shifted to the left because of a pH of 7.6:
  – Hemoglobin will be about 95 percent saturated with oxygen
  – See Figure 6-9
Fig. 6-9. When the PAO$_2$ is 60 mm Hg at a time when the curve has shifted to the left because of a pH of 7.6.
• Although total oxygen increases in the previously mentioned situation:
  – Plasma $\text{PO}_2$ at the tissue sites must decrease more than normal in order for oxygen to dissociate from the hemoglobin
Left Shifts: Unloading of Oxygen at the Tissues

• For example, if the tissue cells require 5 vol% oxygen at a time when the oxygen dissociation curve is normal, the plasma $\text{PO}_2$ will fall from 60 mm Hg to about 35 mm Hg to free 5 vol% of oxygen from the hemoglobin
  – See Figure 6-7
Fig. 6-7. Normally, when the plasma PO$_2$ is 60 mm Hg, the PO$_2$ must fall to about 35 mm Hg to free 5 vol% oxygen for metabolism.
If, however, the curve shifts to the left because of a pH of 7.6:

- Plasma $PO_2$ at tissue sites would have to fall from 60 mm Hg to about 30 mm Hg to unload 5 vol% oxygen from the hemoglobin
- See Figure 6-10
Fig. 6-10. When the plasma $PO_2$ is 60 mm Hg at a time when the curve is to the left because of pH of 7.6, the $PO_2$ must fall to about 30 mm Hg to free 5 vol% oxygen for metabolism.
Oxygen Transport Calculations

• Total Oxygen Delivery
• Arterial-Venous Oxygen Content Difference
• Oxygen Consumption
• Oxygen Extraction Ratio
• Mixed Venous Oxygen Saturation
• Pulmonary Shunting
Total Oxygen Delivery: $\text{DO}_2 = QT \times (\text{CaO}_2 \times 10)$

- The total amount of oxygen delivered or transported to the peripheral tissues is dependent on
  1. The body’s ability to oxygenate blood
  2. The hemoglobin concentration
  3. The cardiac output
Total Oxygen Delivery ($DO_2$) is calculated as follows:

$$DO_2 = QT \times (CaO_2 \times 10)$$
Total Oxygen Delivery

• For example:
  – If a patient has a cardiac output of 5 L/min and a CaO$_2$ of 20 vol% 
  – DO$_2$ will be about 1000 mL of oxygen per minute:
Total Oxygen Delivery

\[ \text{DO}_2 = Q_T \times (\text{CaO}_2 \times 10) \]

\[ = 5 \text{ L/min} \times (20 \text{ vol\%} \times 10) \]

\[ = 1000 \text{ ml O}_2/\text{min} \]

Note: The normal \( \text{DO}_2 \) is about 1000 ml/min
Total Oxygen Delivery

• $\text{DO}_2$ decreases in response to:
  – Low blood oxygenation
    • Low $\text{PaO}_2$
    • Low $\text{SaO}_2$
    • Low hemoglobin concentration
    • Low cardiac output
Total Oxygen Delivery

• $\text{DO}_2$ increases in response to increased blood oxygenation
  – Increased $\text{PaO}_2$
  – Increased $\text{SaO}_2$
  – Increased hemoglobin concentration
  – Increased cardiac output
Arterial-Venous Oxygen Content Difference

\[ \text{C(a-v)O}_2 = \text{CaO}_2 - \text{CvO}_2 \]

- The C(a-v)O\(_2\) is the difference between the CaO\(_2\) and the CvO\(_2\)
Arterial-Venous Oxygen Content Difference

• Normally, the CaO₂ is about 20 vol% and the CvO₂ is 15 vol%.
• Thus, the C(a-v)O₂ is about 5 vol%:
Arterial-Venous Oxygen Content Difference

\[
C(a-v)O_2 = CaO_2 - CvO_2 \\
= 20 \text{ vol}\% - 15 \text{ vol}\% \\
= 5 \text{ vol}\% \\

\text{Normally, 5 vol}\%
Oxygen Dissociation Curve

Fig. 6-11. Oxygen dissociation curve. Summary of important values.
Factors that Increase the C(a-v)O$_2$

- Decreased cardiac output
- Periods of increased oxygen consumption
  - Exercise
  - Seizures
  - Shivering
  - Hyperthermia
Factors that Decrease the C(a-v)O$_2$

- Increased cardiac output
- Skeletal relaxation
  - Induced by drugs
- Peripheral shunting
  - Sepsis, trauma
Factors that Decrease the $\text{C(a-v)O}_2$

- Certain poisons
  - Cyanide
- Hypothermia
Oxygen Consumption

- Amount of oxygen extracted by the peripheral tissues during the period of one minute
- Also called oxygen uptake (VO$_2$)
Oxygen Consumption

• Calculated as follows:

\[ VO_2 = Q_T \times [C(a-v)O_2 \times 10] \]

• Case: If a patient has a cardiac output of 5 L/min and a \( C(a-v)O_2 \) of 5 vol%:
  – What is the total amount of oxygen consumed by the tissue cells in one minute?
Oxygen Consumption

• For example:

• If an individual has a cardiac output of 5 L/min and a $\text{C}(\text{a-v})\text{O}_2$ of 5 vol% 
  – Total amount of oxygen metabolized by the tissue cells in one minute will be 250 mL:
Oxygen Consumption

\[ VO_2 = Q_T \times [C(a-v)O_2 \times 10] \]

\[ = 5 \text{ L/min} \times 5 \text{ vol}\% \times 10 \]

\[ = 250 \text{ ml O}_2/\text{min} \]

Note: The VO\(_2\) is normally about 250 ml O\(_2\)/min
Factors that Increase VO$_2$

- Exercise
- Seizures
- Shivering
- Hyperthermia
- Body Size
Factors that Decrease VO$_2$

- Skeletal Muscle Relaxation
  - Induced by drugs
- Peripheral shunting
  - Sepsis, trauma
- Certain poisons
  - Cyanide
- Hypothermia
Oxygen Extraction Ratio

- Oxygen extraction ratio (O$_2$ER) is the amount of oxygen extracted by the peripheral tissues divided by the amount of oxygen delivered to the peripheral cells.

- Also called:
  - Oxygen coefficient ratio
  - Oxygen utilization ratio
Oxygen Extraction Ratio Calculated as follows:

\[
O_{2}\text{ER} = \frac{\text{CaO}_2 - \text{CvO}_2}{\text{CaO}_2}
\]
Oxygen Extraction Ratio Calculated as Follows:

• In considering the normal CaO$_2$ of 20 vol% and the normal CvO$_2$ of 15 vol%:
• O$_2$ER is about 25 percent
Oxygen Extraction Ratio

\[ O_{2ER} = \frac{CaO_2 - CvO_2}{CaO_2} \]

\[ = \frac{20 \text{ vol}\% - 15 \text{ vol}\%}{20 \text{ vol}\%} \]

\[ = \frac{5 \text{ vol}\%}{20 \text{ vol}\%} \]

\[ = 0.25 \]
Oxygen Extraction Ratio

- $O_2$ER provides an important view of the oxygen transport status when $O_2$ consumption remains the same.

- For example, consider the following two cases with the same C(a-v)$O_2$ (5 vol%), but with different $DO_2$. 
Normal CaO$_2$ and CvO$_2$

\[
\begin{align*}
\text{CaO}_2 & \quad 20 \ \text{vol}\% \\
- \text{CvO}_2 & \quad 15 \ \text{vol}\% \\
\text{C(a-v)O}_2 & \quad 5 \ \text{vol}\%
\end{align*}
\]

The O$_2$ER = 25%
Decreased CaO$_2$ and CvO$_2$

\[
\begin{align*}
\text{CaO}_2 & \quad 10 \text{ vol}\% \\
- \text{CvO}_2 & \quad 5 \text{ vol}\% \\
\hline
\text{C(a-v)O}_2 & \quad 5 \text{ vol}\%
\end{align*}
\]

The O$_2$ER = 50\%
Factors that Increase $O_2$ER

- Decreased cardiac output
- Periods of increased $O_2$ consumption
  - Exercise
  - Seizures
  - Shivering
  - Hyperthermia
  - Anemia
Factors that Decrease $O_2ER$

- Increased cardiac output
- Skeletal muscle relaxation
  - Drug induced
- Peripheral shunting (e.g., sepsis)
Factors that Decrease O$_2$ER

- Certain poisons
  - Cyanide
- Hypothermia
- Increased Hb
- Increased arterial oxygenation (PaO$_2$)
Mixed Venous Oxygen Saturation (SvO₂)

• Changes in the SvO₂ can be used to detect changes in the:
  – C(a-v)O₂
  – VO₂
  – O₂ER
Factors that Decrease the $\text{SvO}_2$

- Decreased cardiac output
- Exercise
- Seizures
- Shivering
- Hyperthermia
Factors that Increase the $\text{SvO}_2$

• Increased cardiac output
• Skeletal muscle relaxation
  – Drug induced
• Peripheral shunting
  – Sepsis
Factors that Increase the SvO₂

- Certain poisons
  - Cyanide
- Hypothermia
### Table 6-10

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<th>DO₂</th>
<th>VO₂</th>
<th>C(a-v)O₂</th>
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# Oxygen Transport Calculations

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### Oxygen Transport Calculations

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<th>DO₂</th>
<th>VO₂</th>
<th>C(a-v)O₂</th>
<th>O₂ER</th>
<th>SvO₂</th>
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<tr>
<td>Peripheral shunting</td>
<td>Same</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
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</table>
## Oxygen Transport Calculations

### Table 6-10

<table>
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<tr>
<th>Clinical Factors</th>
<th>$\text{DO}_2$</th>
<th>$\text{VO}_2$</th>
<th>$\text{C(a-v)O}_2$</th>
<th>$\text{O}_2\text{ER}$</th>
<th>$\text{SvO}_2$</th>
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<td>Certain Poisons</td>
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<td>$\downarrow$</td>
<td>$\downarrow$</td>
<td>$\uparrow$</td>
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Pulmonary Shunting

• Portion of cardiac output that moves from the right side to the left side of the heart without being exposed to alveolar oxygen (PAO$_2$).
Pulmonary Shunting

• Clinically, pulmonary shunting can be subdivided into:
  – Absolute Shunt
  – Also called True Shunt

• Relative Shunt
  – Also called shunt-like effects
Absolute Shunt

• An anatomic shunt (true shunt)
  – When blood flows from the right side of heart to the left side without coming in contact with an alveolus for gas exchange
  – See Figure 6-12, A and B
Pulmonary Shunting

Fig. 6-12. Pulmonary shunting.
Common Causes of Absolute Shunting

- Congenital heart disease
- Intrapulmonary fistula
- Vascular lung tumors
Common Causes of Absolute Shunting

• Capillary shunting is commonly caused by:
  – Alveolar collapse or atelectasis
  – Alveolar fluid accumulation
  – Alveolar consolidation
    • See Figure 6-12, C
Common Causes of Absolute Shunting

• When pulmonary capillary perfusion is in excess of alveolar ventilation, a relative or shunt-like effect is said to exist
  – See Figure 6-12, D
Common Causes of This Form of Shunting

• Hypoventilation
• Ventilation/perfusion mismatches
  – Chronic emphysema, bronchitis, asthma
• Alveolar-capillary diffusion defects
  – Alveolar fibrosis or alveolar edema
• Venous mixture is the mixing of shunted, non-reoxygenated blood with reoxygenated blood distal to the alveoli
  – Downstream in the pulmonary venous system
  – See Figure 6-13
Venous Admixture occurs when reoxygenated blood mixes with non-reoxygenated blood.
Pulmonary Equation

\[ \frac{Q_S}{Q_T} = \frac{CcO_2 - CaO}{CcO_2 - CvO_2} \]
Shunt Equation Clinical Information Needed

- PB
- \( \text{PaO}_2 \)
- \( \text{PaCO}_2 \)
- \( \text{PvO}_2 \)
- Hb
- \( \text{PAO}_2 \)
- \( \text{PAO}_2 \)
- \( \text{FIO}_2 \)
Case Study: Motorcycle Accident Victim

- A 38-year-old man is on a volume-cycled mechanical ventilator on a day when the barometric pressure is 750 mm Hg
- Patient is receiving an FIO$_2$ of .70
  - The following clinical data are obtained:
Case Study: Motorcycle Accident Victim

- Hb: 13 g%
- PaO$_2$: 50 mm Hg (SaO$_2$ = 85%)
- PaCO$_2$: 43 mm Hg
- PvO$_2$: 37 mm Hg (SvO$_2$ = 65%)
Case Study: Motorcycle Accident Victim

• With this information, the patient’s PAO$_2$, CcO$_2$, CaO$_2$, and CvO$_2$ can now be calculated.
Case Study: Motorcycle Accident Victim

1. \[ PAO_2 = (PB - PH_2O) FIO_2 - PaCO_2 \] (1.25)
   
   = (750 - 47) 0.70 - 43 (1.25)
   
   = (703) 0.70 - 53.75
   
   = 492.1 - 53.75
   
   = 438.35 \text{ mm Hg}
2. $\text{CcO}_2 = (\text{Hb} \times 1.34) + (\text{PAO}_2 \times 0.003)$

$\quad = (13 \times 1.34) + (438.35 \times 0.003)$

$\quad = 17.42 + 1.315$

$\quad = 18.735 \text{ (vol\% O}_2)$
3. \( \text{CaO}_2 = (\text{Hb} \times 1.34 \times \text{SaO}_2) + (\text{PaO}_2 \times 0.003) \)

\[
= (13 \times 1.34 \times .85) + (50 \times 0.003)
\]

\[
= 14.807 + 0.15
\]

\[
= 14.95 \text{ (vol\% O}_2\text{)}
\]
4. \[ \text{CaO}_2 = (\text{Hb} \times 1.34 \times \text{SvO}_2) + (\text{PvO}_2 \times 0.003) \]

\[ = (13 \times 1.34 \times 0.65) + (37 \times 0.003) \]

\[ = 11.323 + 0.111 \]

\[ = 11.434 \text{ (vol\% O}_2) \]
• Based on the previous calculation the patient’s degree of pulmonary shunting can now be calculated:

\[
\begin{align*}
Q_s &= \frac{CcO_2 - CaO_2}{CcO_2 - CvO_2} \\
Q_T &= \frac{CcO_2 - CvO_2}{18.375 - 11.434} \\
&= \frac{18.735 - 14.957}{3.778} \\
&= \frac{7.301}{7.301} \\
&= 0.515
\end{align*}
\]
Clinical Significance of Pulmonary Shunting

- <10%
  - Normal status
- 10 to 20%
  - Indicates intrapulmonary abnormality
Clinical Significance of Pulmonary Shunting

- 20 to 30%
  - Significant intrapulmonary diseases
- > 30%
  - Potentially life-threatening
Appendix V

Oxygen Transport Status

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<thead>
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<th>mL O₂/min</th>
<th>%O₂</th>
<th>Ca-O₂</th>
<th>%O₂ in</th>
<th>%O₂</th>
<th>%O₂</th>
<th>%O₂</th>
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</tbody>
</table>

Blood Gas Values

- pH
- PaO₂
- PaCO₂
- HCO₃⁻
- SaO₂
- SpO₂
- FiO₂
- Hb

Mode(s) of Ventilatory Support:

---

Shaded areas represent normal ranges.

Patient's Name: ______________________
Date: ______________________
Time: ______________________
HYPOXIA
HYPOXEMIA VERSUS HYPOXIA
Hypoxemia

- Abnormally low arterial oxygen tension (PaO$_2$)
- Frequently associated with hypoxia
  - Which is an inadequate level of tissue oxygenation
## Hypoxemia Classifications

<table>
<thead>
<tr>
<th>Classifications</th>
<th>PaO₂ (rule of thumb)</th>
</tr>
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<tbody>
<tr>
<td>Normal</td>
<td>80-100 mm Hg</td>
</tr>
<tr>
<td>Mild hypoxemia</td>
<td>60-80 mm Hg</td>
</tr>
<tr>
<td>Moderate hypoxemia</td>
<td>40-60 mm Hg</td>
</tr>
<tr>
<td>Severe hypoxemia</td>
<td>&lt;40 mm Hg</td>
</tr>
</tbody>
</table>
Hypoxia

• Low or inadequate oxygen for cellular metabolism
There are four main types of hypoxia:
- Hypoxic
- Anemic
- Circulatory
- Histotoxic
Types of Hypoxia

• Hypoxic hypoxia
  – Inadequate oxygen at tissue cells caused by low arterial oxygen tension (PaO$_2$)
  – Common Causes
    • Low PaO$_2$ caused by
      – Hypoventilation
      – High altitude
Types of Hypoxia

• Hypoxic hypoxia
  – Diffusion defects
  – Ventilation-perfusion mismatch
  – Pulmonary shunting
• Anemic hypoxia
  – $\text{PaO}_2$ is normal, but the oxygen carrying capacity of the hemoglobin is inadequate
Types of Hypoxia

• Anemic hypoxia
  – Common Causes
    • Decreased hemoglobin
    • Anemia
    • Hemorrhage
    • Abnormal hemoglobin
      – Carboxyhemoglobinemia
      – Methemoglobinemia
Types of Hypoxia

• Circulatory hypoxia
  – Stagnant hypoxia or hypoperfusion
  – Blood flow to the tissue cells is inadequate
    • Thus, oxygen is not adequate to meet tissue needs
Types of Hypoxia

• Circulatory hypoxia
  – Common causes
    • Slow or stagnant (pooling) peripheral blood flow
    • Arterial-venous shunts
• Histotoxic hypoxia
  – Impaired ability of the tissue cells to metabolize oxygen
  – Common cause
    • Cyanide poisoning
Cyanosis

• Blue-gray or purplish discoloration seen on the mucous membranes, fingertips, and toes
  – Blood in these areas contain at least 5 g% of reduced hemoglobin
Cyanosis

Fig. 6-14. Cyanosis may appear whenever the blood contains at least 5 g% of reduced hemoglobin.
Polycythemia

• An increased level of RBCs
• An adaptive mechanism designed to increase the oxygen-carrying capacity of the blood
Clinical Application 1 Discussion

• How did this case illustrate …
  – The importance of hemoglobin in the oxygen transport system
Asthma

Fig. 6-15. Asthma. Pathology includes (1) bronchial smooth muscle constriction, (2) inflammation and excessive production of thick, whitish bronchial secretions, and (3) alveolar hyperinflation.
Clinical Application 2 Discussion

• How did this case illustrate …
  – The loading of oxygen on hemoglobin in the lung?
  – The patient’s total oxygen delivery ($DO_2$)?