Cardiopulmonary Anatomy & Physiology

Essentials of Respiratory Care

Fifth Edition

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CHAPTER 6

Oxygen Transport

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Normal Blood Gas Value Ranges

Table 6-1

Blood Gas Value	Arterial	Venous
pH	7.35-7.4	7.30-7.40
PCO_2	35-45 mm Hg	42-48 mmHg
HCO_3	22-28 mEq/L	24-30 mEq/L
PO_2	80-100 mmHg	35-45 mm Hg

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OXYGEN TRANSPORT

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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

$$\text{Vol\%} = \text{mL } O_2/100 \text{ mL bd}$$

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Oxygen Dissolved in the Blood Plasma

- For example:
  - 10 vol% of O_2 means that there are 10 mL of 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

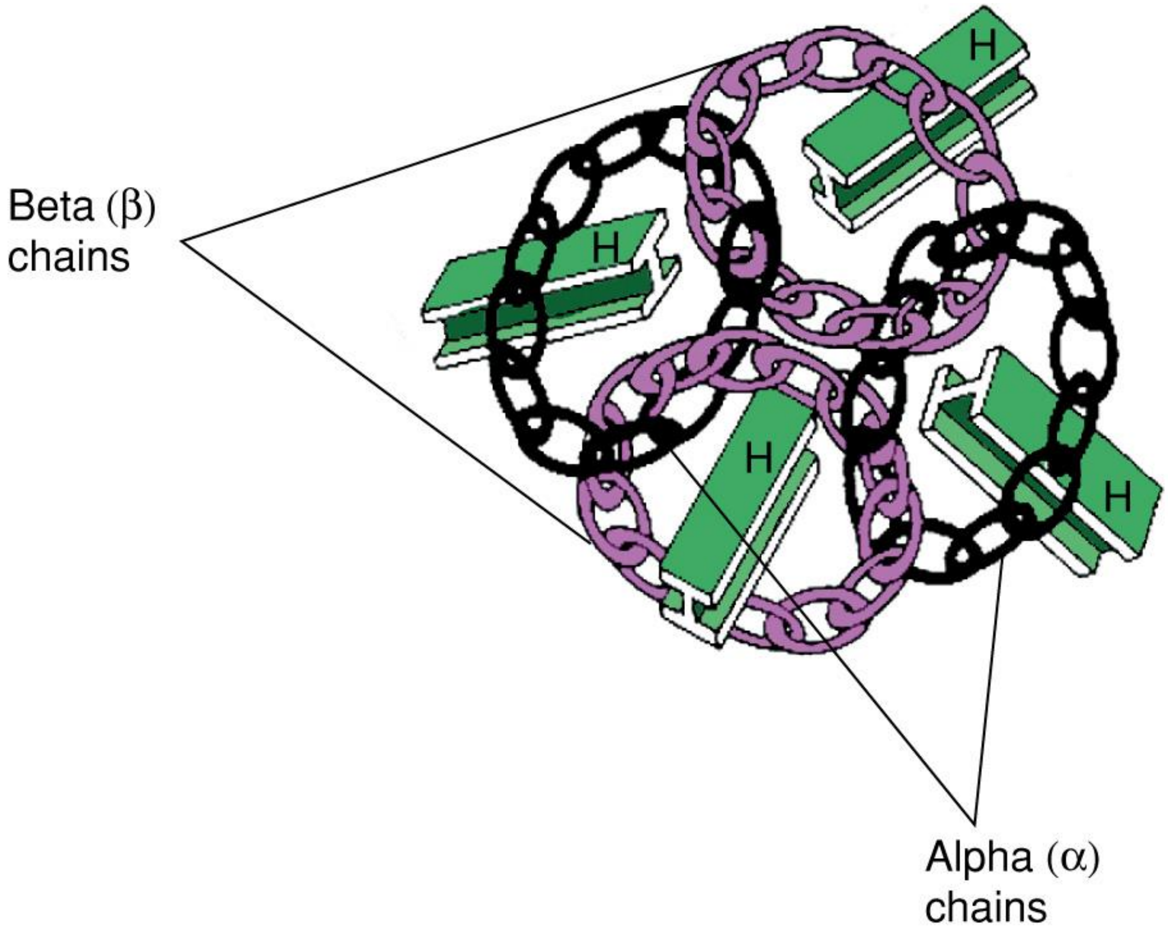

Fig. 6-1. Schematic illustration of a hemoglobin molecule.

Oxygen Bound to Hemoglobin

$$Hb + O_2 \rightleftharpoons HbO_2$$

Hb	+	O_2		HbO_2
Reduced hemoglobin (uncombined or deoxygenate hemoglobin)		Oxygen		Oxyhemoglobin (combined or oxygenated hemoglobin)

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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

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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)

Quantity of Oxygen Bound to Hemoglobin

- 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

$$O_2 \text{ bound to Hb} = 1.34 \text{ mL } O_2 \times 15 \text{ g\% Hb}$$

$$= 20.1 \text{ vol\% } O_2$$

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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

Quantity of Oxygen Bound to Hemoglobin

- Thus, the amount of arterial oxygen in the preceding equation must be adjusted to 97 percent:

$$\begin{array}{l} 20.1 \text{ vol\% } O_2 \\ \times\ 0.97 \\ \hline 19.5 \text{ vol\% } O_2 \end{array}$$

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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

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Total Oxygen Content

- The following case study summarizes the calculations required to compute an individual's total oxygen content

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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%)

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Case Study—Anemic Patient

- Based on this information, the patient's total oxygen content is computed as follows:
  1. Dissolved O_2:

$$\begin{array}{l} 80\ PaO_2 \\ \times\ 0.003\ (\text{dissolved } O_2 \text{ factor}) \\ \hline 0.24\ \text{vol\%}\ O_2 \end{array}$$

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Case Study - Anemic Patient

2. Oxygen Bound to Hemoglobin:

   6 g% Hb

   x 1.34 (O_2 bound to Hb factor)

   8.04 vol% O_2 (at SaO_2 of 100%)

   8.04 vol% O_2

   x 0.90 SaO_2

   7.236 vol% O_2

Case Study—Anemic Patient

3. Total oxygen content:

$$
\begin{array}{rl}
 & 7.236 \text{ vol\% } O_2 \text{ (bound to hemoglobin)} \\
+ & 0.24 \text{ vol\% } O_2 \text{ (dissolved } O_2\text{)} \\
\hline
 & 7.476 \text{ vol\% } O_2 \text{ (total amount of } O_2\text{/100 ml of blood)}
\end{array}
$$

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

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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

- CaO_2 = Oxygen content of arterial blood

$$(Hb \times 1.34 \times SaO_2) + (PaO_2 \times 0.003)$$

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Total Oxygen Content of Mixed Venous Blood

- CvO_2 = Oxygen content of mixed venous blood

$$(Hb \times 1.34 \times SvO_2) + (PvO \times 0.003)$$

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Total Oxygen Content of Pulmonary Capillary Blood

- CcO_2 = Oxygen content of pulmonary capillary blood

$$(Hb \times 1.34) + (PAO_2 \times 0.003)$$

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Total Oxygen Content

- It will be shown later how various mathematical manipulations of the CaO_2, CvO_2, and CcO_2 values are used in different oxygen transport studies to reflect important factors concerning the patient's cardiac and ventilatory status.

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OXYGEN DISSOCIATION CURVE

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Oxygen Dissociation Curve

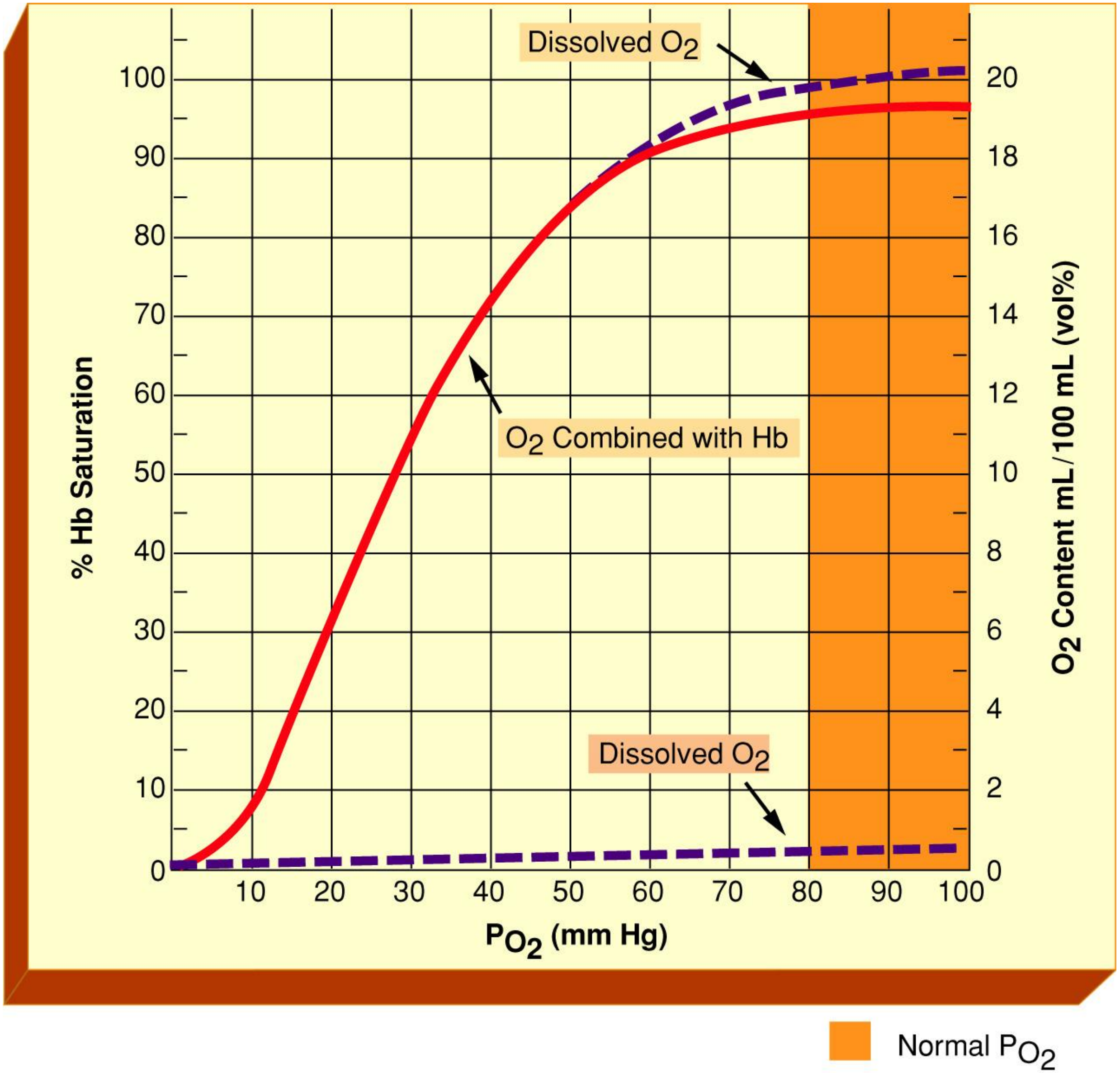

Fig. 6-2. Oxygen dissociation curve.

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Clinical Significance of the Flat Portion of the 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 O_2 has transferred
  - This enhances the diffusion of O_2

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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)

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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

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The P_{50}

- P_{50} represents the partial pressure at which the hemoglobin is 50 percent saturated with oxygen
- Normally, P_{50} is about 27 mm Hg

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The P_{50}

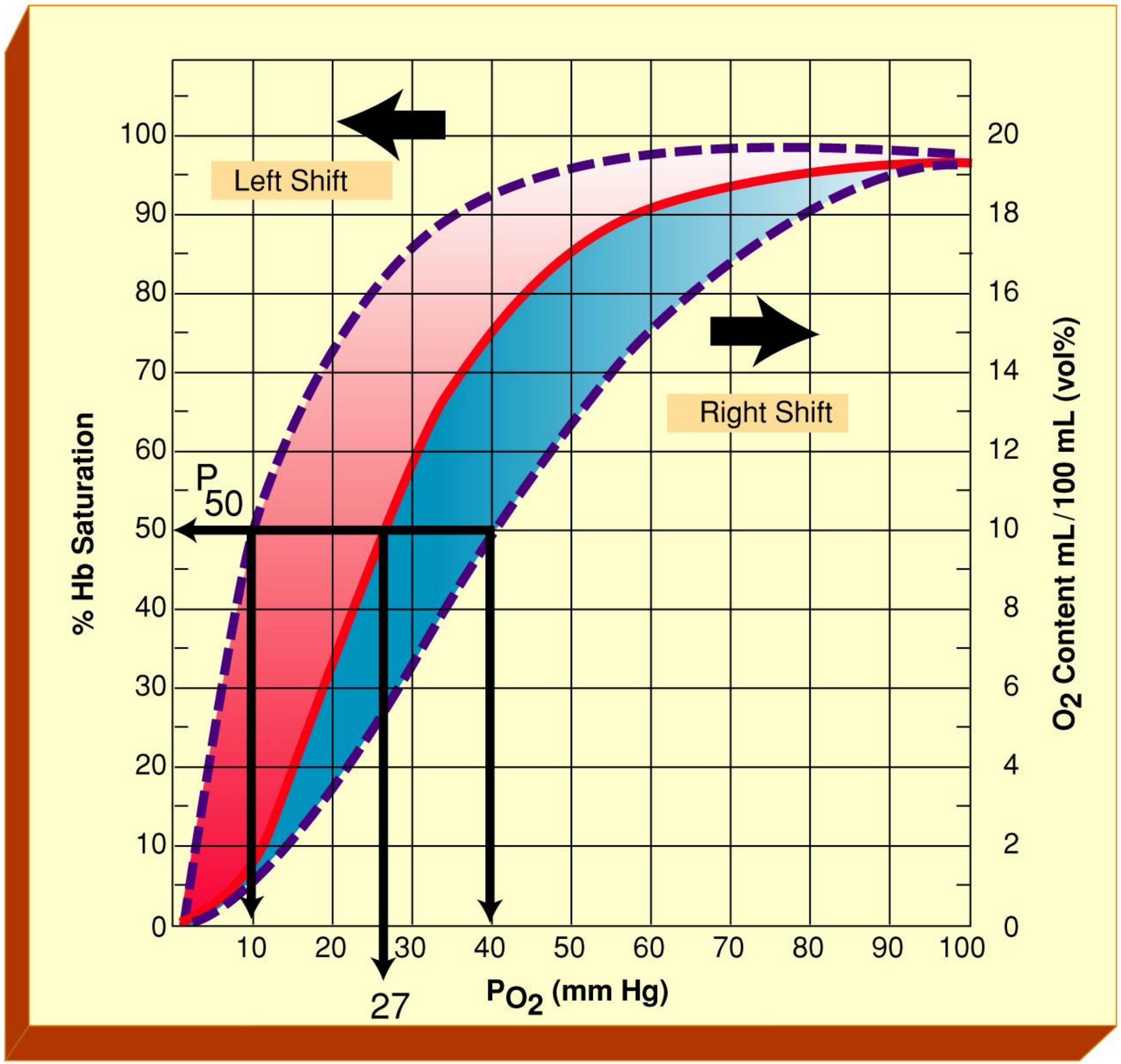

Fig. 6-3. The P_{50} represents the partial pressure at which hemoglobin is 50 percent saturated with oxygen.

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Factors that Shift Oxygen Dissociation Curve

- pH
- Temperature
- Carbon Dioxide
- 2,3-DPG
- Fetal Hemoglobin
- Carbon Monoxide Hemoglobin

Oxygen Dissociation Curve

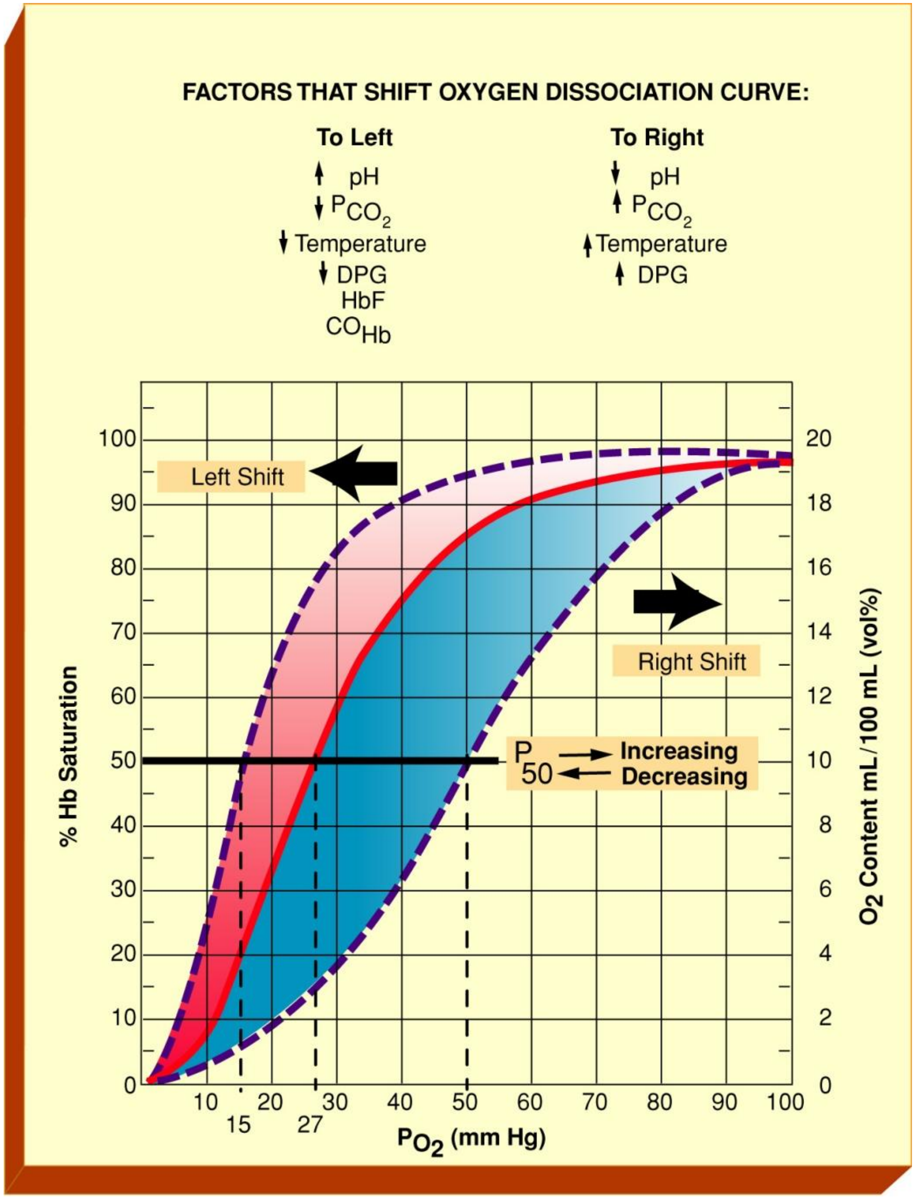

Fig. 6-4. Factors that shift the oxygen dissociation curve to the right and left.

CLINICAL SIGNIFICANCE OF SHIFTS IN THE O_2 DISSOCIATION CURVE

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.

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The O_2 Dissociation Curve

- However, when an individual's blood PaO_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 O_2 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.

Right Shifts: Loading of Oxygen in Lungs

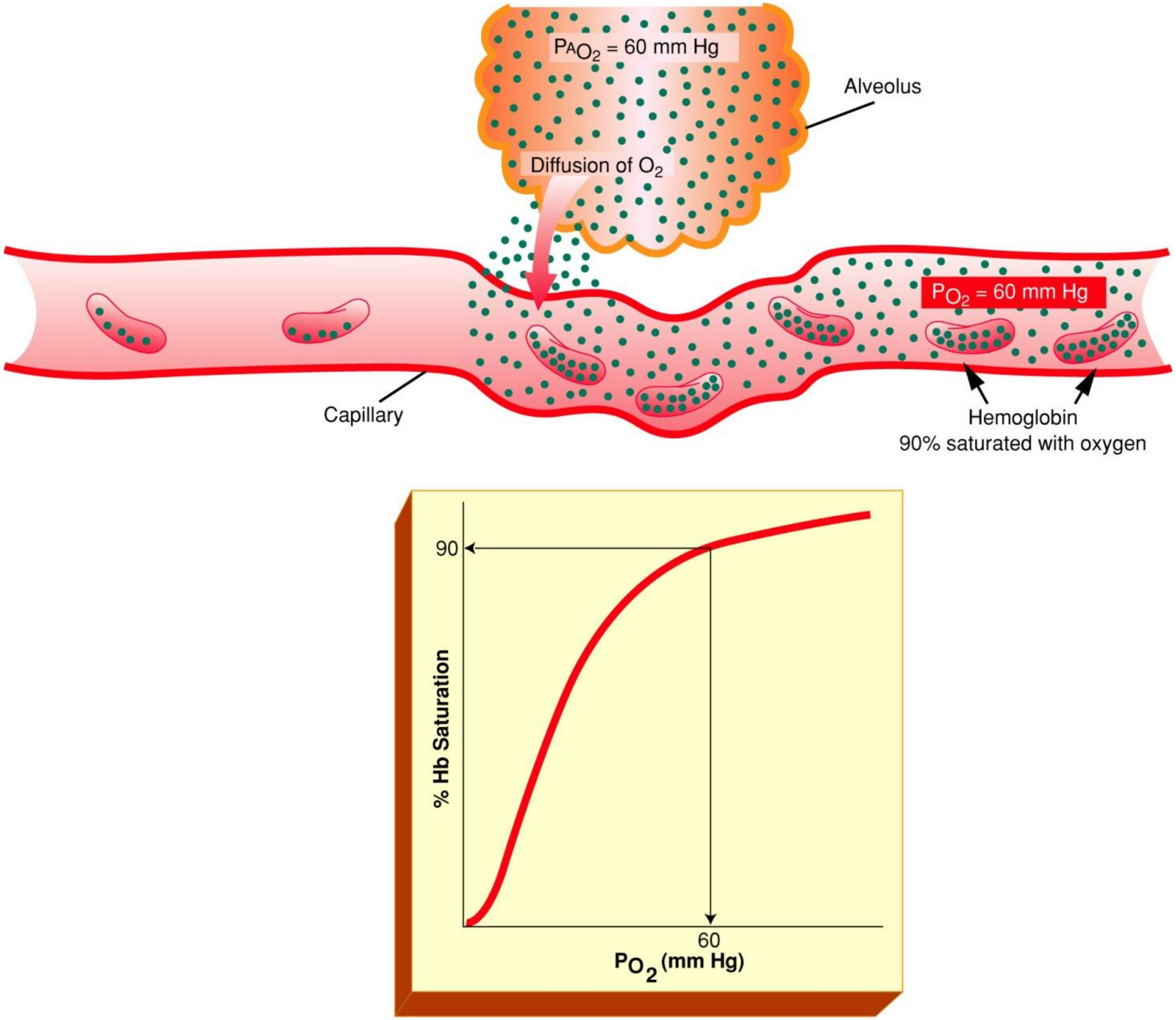

Fig. 6-5. Normally, when the PaO_2 is 60 mm Hg, the plasma PO_2 is about 60 mm Hg, and Hb is about 90% saturated.

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Right Shifts: Loading of Oxygen in Lungs

- 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.

Right Shifts: Loading of Oxygen in Lungs

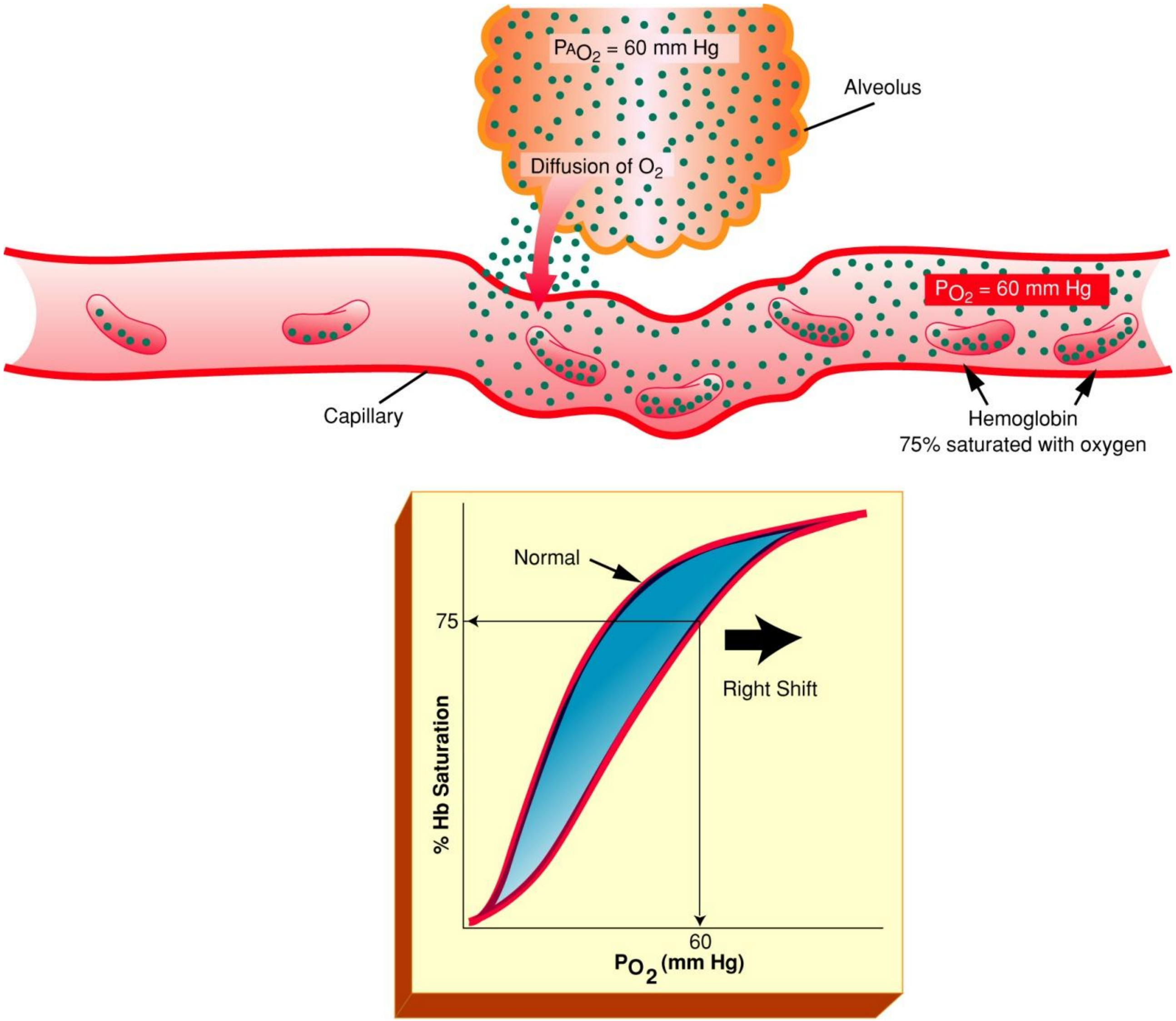

Fig. 6-6. When the PAO_2 is 60 mm Hg at a time when the curve has shifted to the right because of a pH of 7.1.

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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 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

Right Shifts: Unloading of Oxygen at the Tissues

- 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

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Right Shifts: Unloading of Oxygen at the Tissues

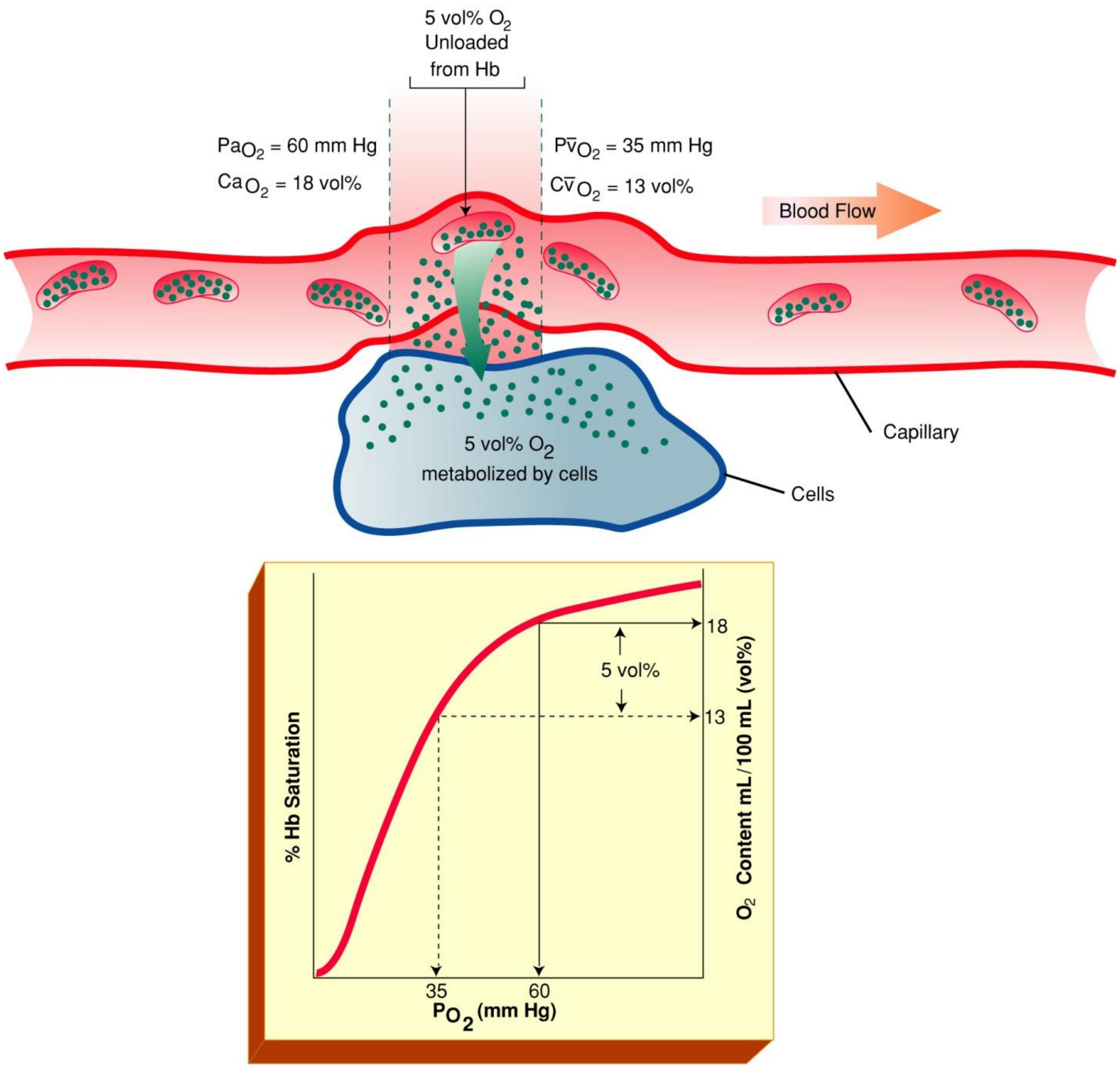

Fig. 6-7. Normally, when the plasma PO_2 is 60 mm Hg, the PO_2 must fall to about 35 mm Hg to free 5 vol% oxygen for metabolism.

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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

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Right Shifts: Unloading of Oxygen at the Tissues

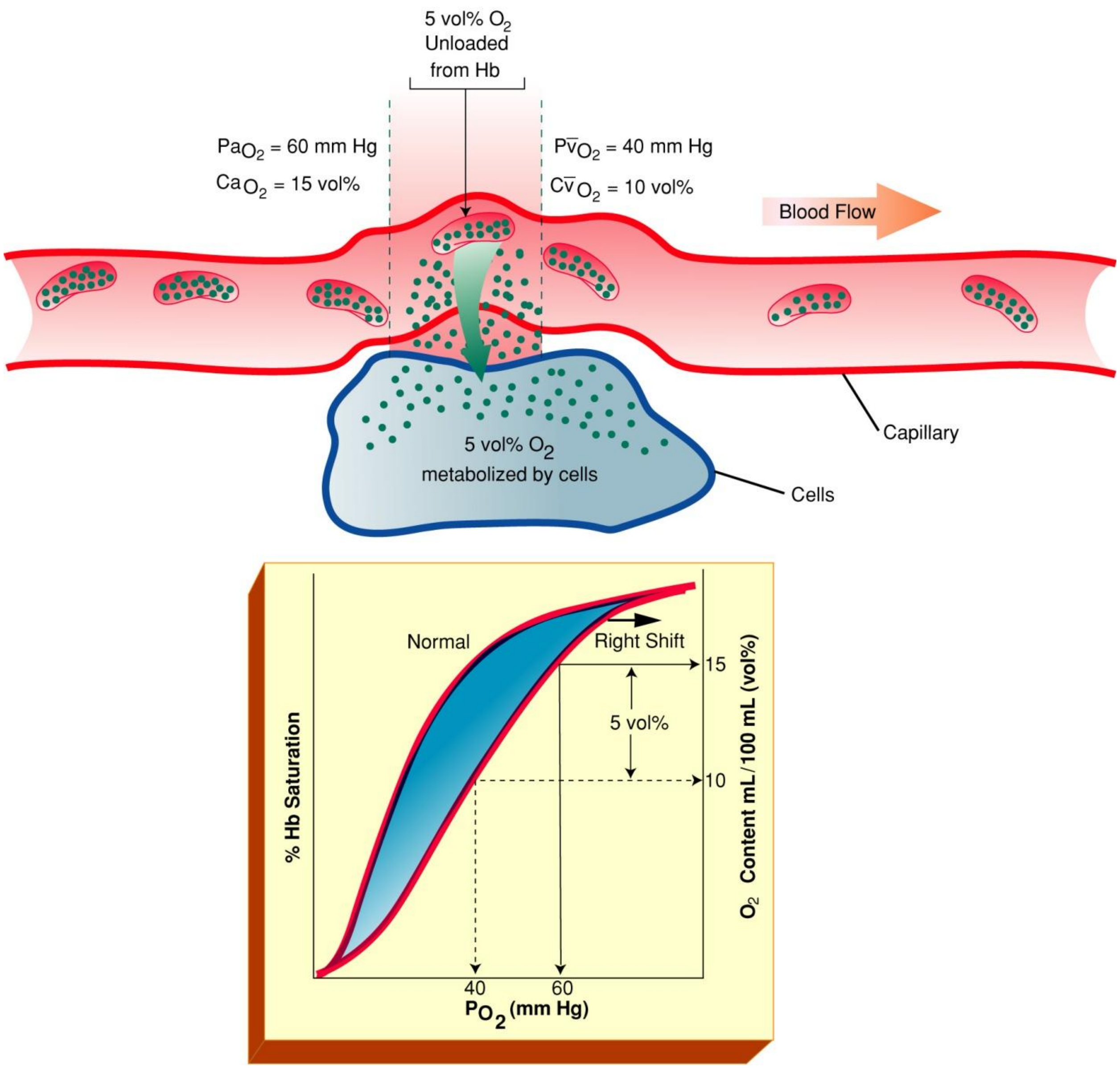

Fig. 6-8. When the plasma PO_2 is 60 mm Hg at a time when the curve is to the right because of pH of 7.1, the PO_2 must fall to about 40 mm Hg to free 5 vol% oxygen for metabolism.

Left Shifts: Loading of Oxygen in the Lungs

- If the oxygen dissociation curve shifts to left 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:
  - Hemoglobin will be about 95 percent saturated with oxygen
  - See Figure 6-9

Left Shifts: Loading of Oxygen in the Lungs

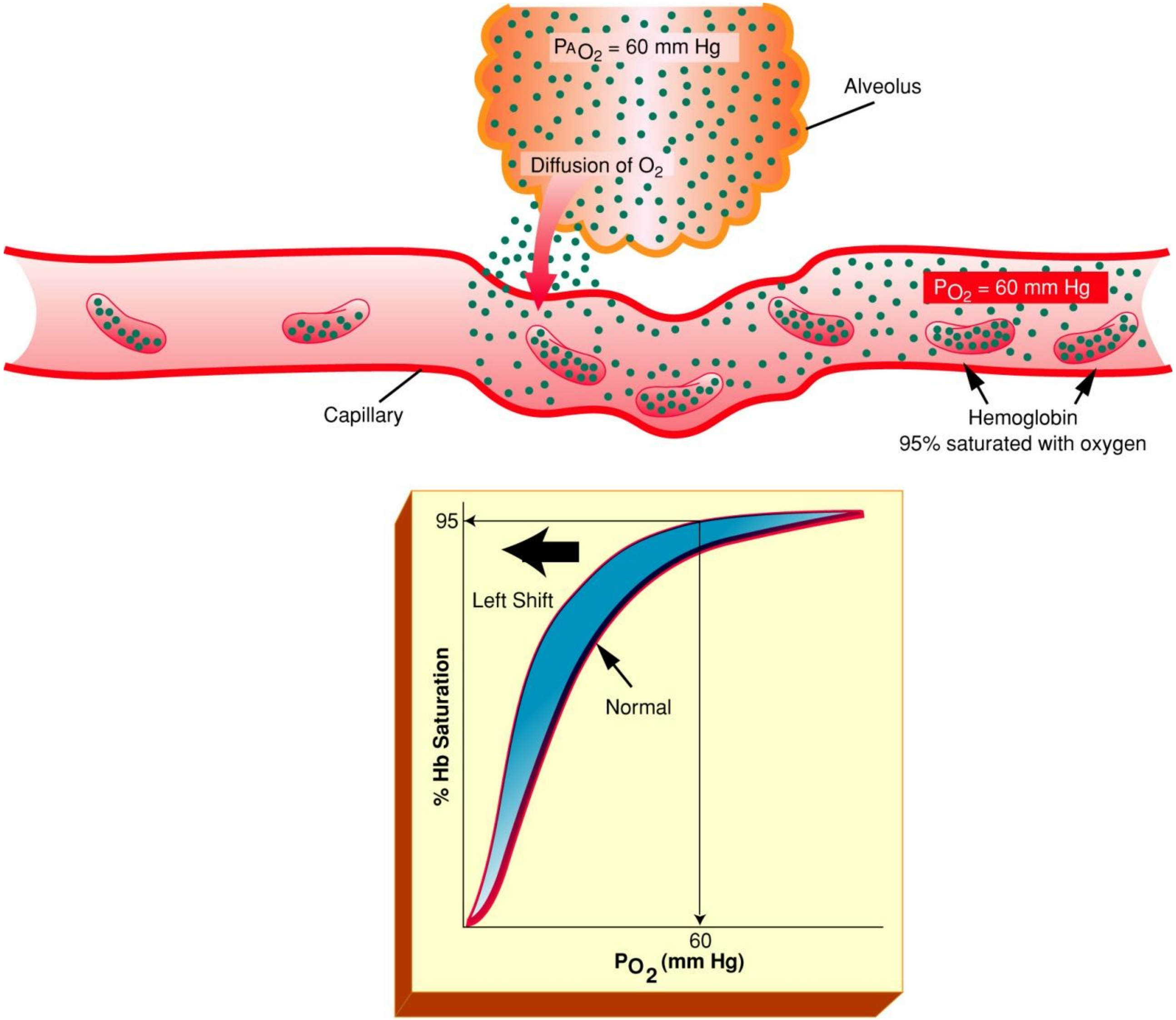

Fig. 6-9. When the PAO_2 is 60 mm Hg at a time when the curve has shifted to the left because of a pH of 7.6.

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Left Shifts: Unloading of Oxygen at the Tissues

- Although total oxygen increases in the previously mentioned situation:
  - Plasma PO_2 at the tissue sites must decrease more than normal in order for oxygen to dissociate from the hemoglobin

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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 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

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Oxygen for Metabolism

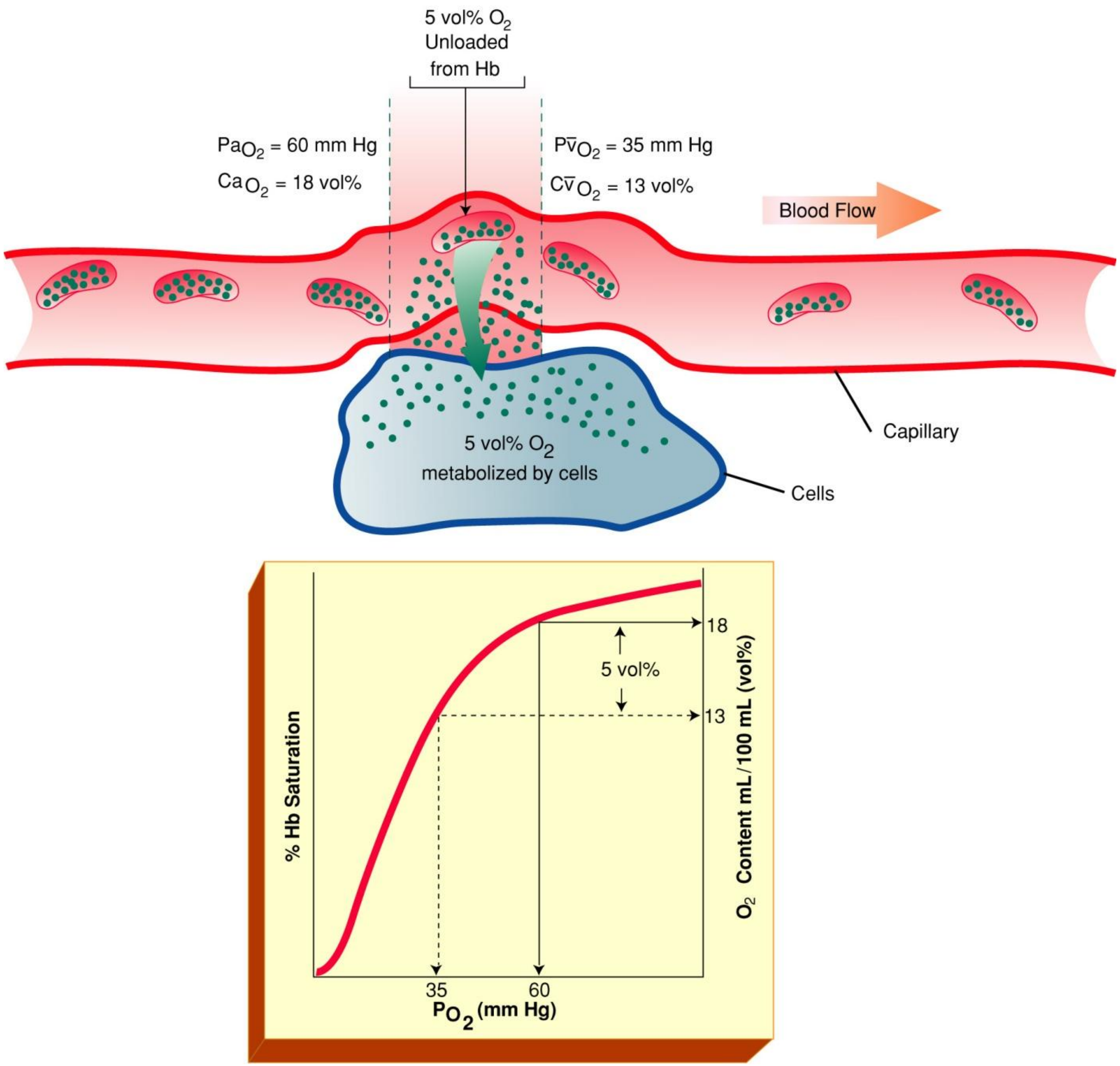

Fig. 6-7. Normally, when the plasma PO_2 is 60 mm Hg, the PO_2 must fall to about 35 mm Hg to free 5 vol% oxygen for metabolism.

Left Shifts: Unloading of Oxygen at the Tissues

- 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

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Left Shifts: Unloading of Oxygen at the Tissues

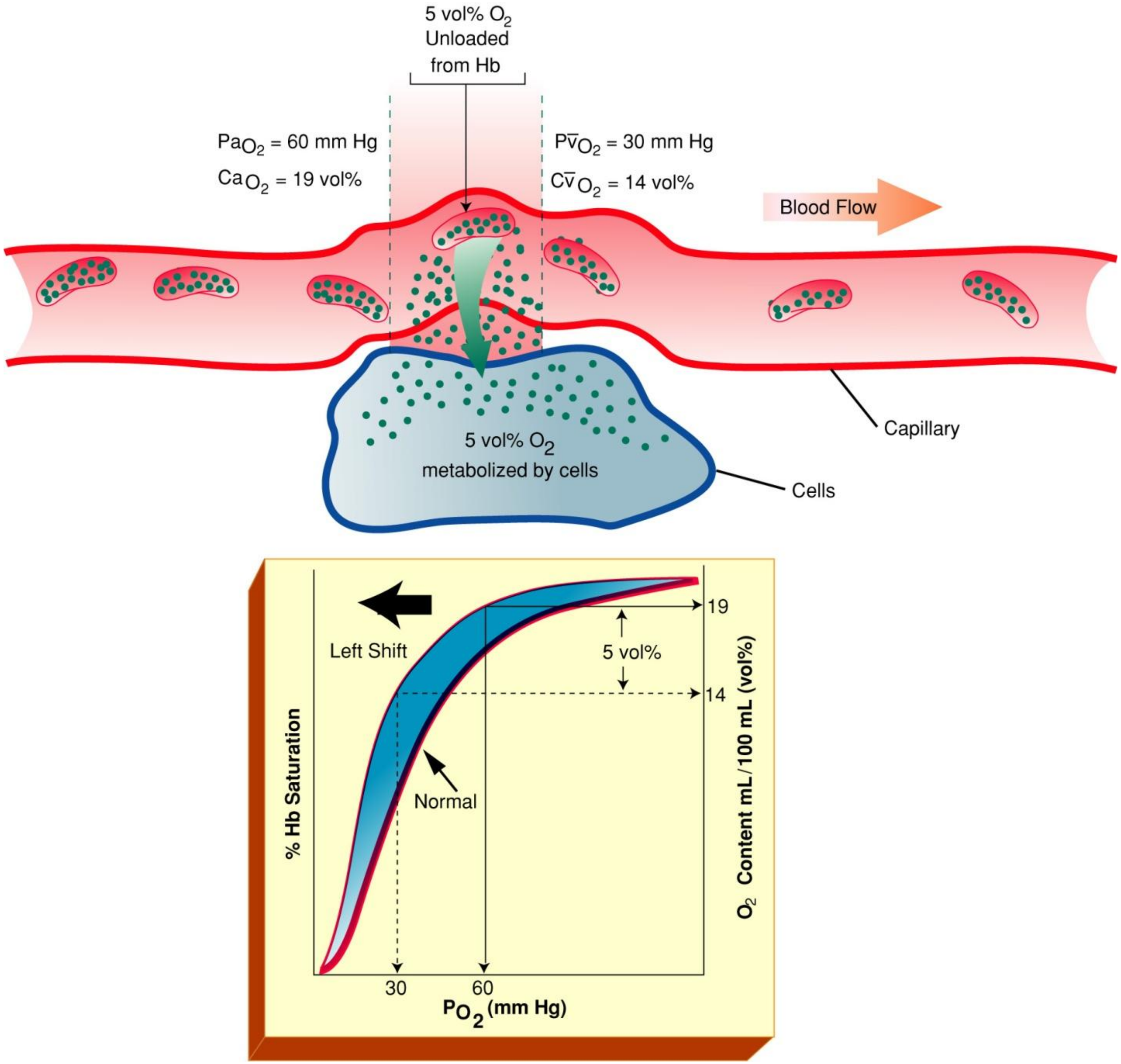

Fig. 6-10. When the plasma PO_2 is 60 mm Hg at a time when the curve is to the left because of pH of 7.6, the PO_2 must fall to about 30 mm Hg to free 5 vol% oxygen for metabolism.

Oxygen Transport Calculations

- Total Oxygen Delivery
- Arterial-Venous Oxygen Content Difference
- Oxygen Consumption
- Oxygen Extraction Ratio
- Mixed Venous Oxygen Saturation
- Pulmonary Shunting

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

- 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

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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:

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Total Oxygen Delivery

$$DO_2 = Q_T \text{ x } (CaO_2 \text{ x } 10)$$

$$= 5 \text{ L/min x } (20 \text{ vol\% x } 10)$$

$$= 1000 \text{ ml } O_2\text{/min}$$

Note: The normal DO_2 is about 1000 ml/min

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Total Oxygen Delivery

- DO_2 decreases in response to:
  - Low blood oxygenation
    - Low PaO_2
    - Low SaO_2
    - Low hemoglobin concentration
    - Low cardiac output

Total Oxygen Delivery

- DO_2 increases in response to increased blood oxygenation
  - Increased PaO_2
  - Increased SaO_2
  - Increased hemoglobin concentration
  - Increased cardiac output

Arterial-Venous Oxygen Content Difference

$$C(a\text{-}v)O_2 = CaO_2 - CvO_2$$

- The $C(a\text{-}v)O_2$ is the difference between the CaO_2 and the CvO_2

Arterial-Venous Oxygen Content Difference

- Normally, the CaO_2 is about 20 vol% and the CvO_2 is 15 vol%.
- Thus, the $C(a\text{-}v)O_2$ is about 5 vol%:

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Arterial-Venous Oxygen Content Difference

$$C(a\text{-}v)O_2 = CaO_2 - CvO_2$$

$$= 20 \text{ vol\%} - 15 \text{ vol\%}$$

$$= 5 \text{ vol\%}$$

Normally, 5 vol%

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Oxygen Dissociation Curve

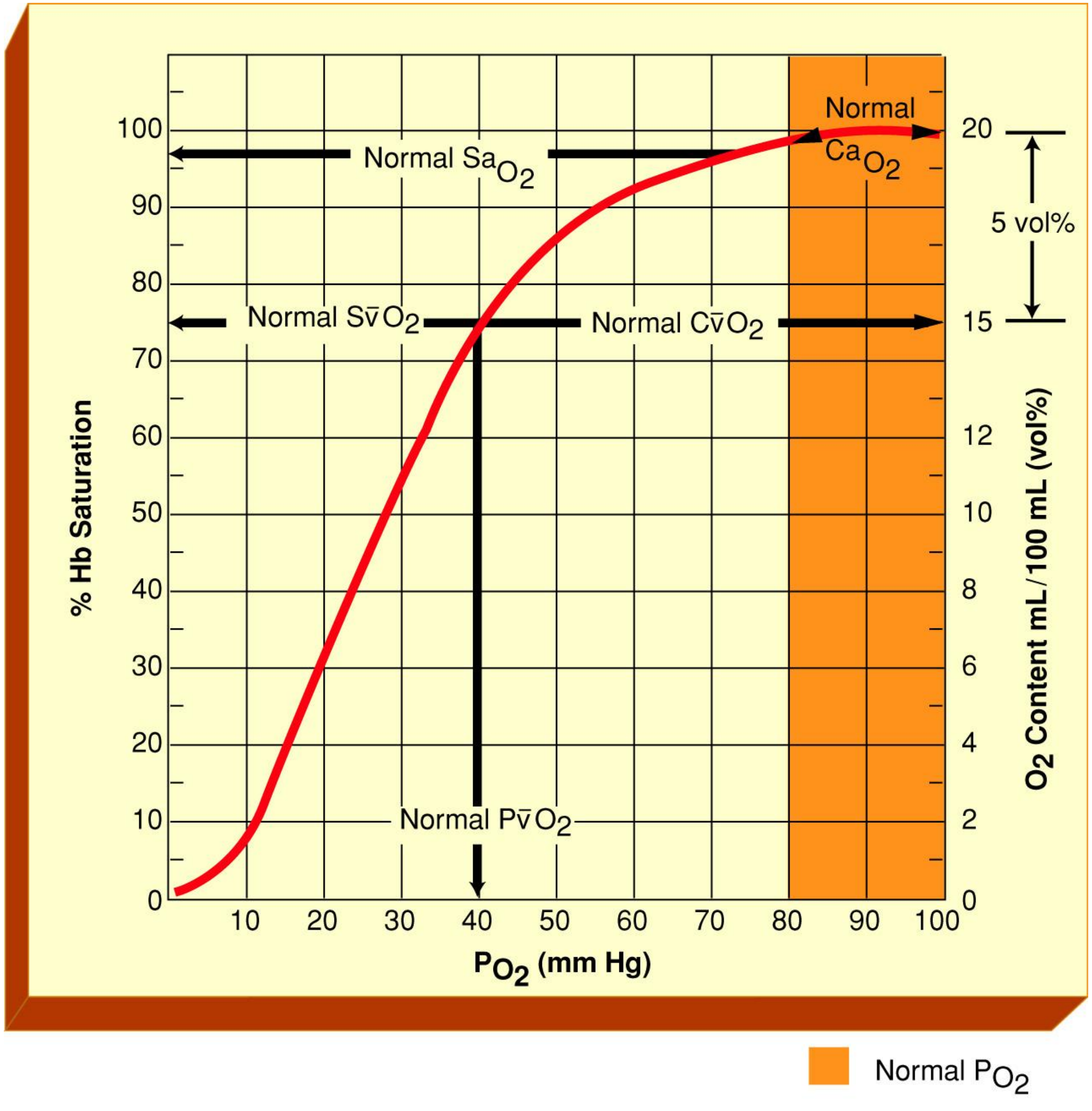

Fig. 6-11. Oxygen dissociation curve. Summary of important values.

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Factors that Increase the $C(a\text{-}v)O_2$

- Decreased cardiac output
- Periods of increased oxygen consumption
  - Exercise
  - Seizures
  - Shivering
  - Hyperthermia

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Factors that Decrease the $C(a\text{-}v)O_2$

- Increased cardiac output
- Skeletal relaxation
  - Induced by drugs
- Peripheral shunting
  - Sepsis, trauma

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Factors that Decrease the $C(a\text{-}v)O_2$

- 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)

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Oxygen Consumption

- Calculated as follows:

$$VO_2 = Q_T\ [C(a\text{-}v)O_2 \times 10]$$

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

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Oxygen Consumption

- For example:
- If an individual has a cardiac output of 5 L/min and a $C(a\text{-}v)O_2$ of 5 vol%
  - Total amount of oxygen metabolized by the tissue cells in one minute will be 250 mL:

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Oxygen Consumption

$$VO_2 = Q_T\,[C(a\text{-}v)O_2 \times 10]$$

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

$$= 250\ \text{ml}\ O_2\text{/min}$$

Note: The VO_2 is normally about 250 ml O_2/min

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Factors that Increase VO_2

- Exercise
- Seizures
- Shivering
- Hyperthermia
- Body Size

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Factors that Decrease VO_2

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

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Oxygen Extraction Ratio

- Oxygen extraction ratio (O_2ER) 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

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Oxygen Extraction Ratio Calculated as Follows:

$$O_2ER = \frac{CaO_2 - CvO_2}{CaO_2}$$

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Oxygen Extraction Ratio Calculated as Follows:

- In considering the normal CaO_2 of 20 vol% and the normal CvO_2 of 15 vol%:
- O_2ER is about 25 percent

Oxygen Extraction Ratio

$$O_2ER = \frac{CaO_2 - CvO_2}{CaO_2}$$

$$= \frac{20 \text{ vol\%} - 15 \text{ vol\%}}{20 \text{ vol\%}}$$

$$= \frac{5 \text{ vol\%}}{20 \text{ vol\%}}$$

$$= 0.25$$

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Oxygen Extraction Ratio

- O_2ER 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 $C(a\text{-}v)O_2$ (5 vol%), but with different DO_2

Normal CaO_2 and CvO_2

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

The O_2ER = 25%

Decreased CaO_2 and CvO_2

CaO_2	10 vol%
– CvO_2	5 vol%
$C(a\text{-}v)O_2$	5 vol%

The O_2ER = 50%

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Factors that Increase O_2ER

- Decreased cardiac output
- Periods of increased O_2 consumption
  - Exercise
  - Seizures
  - Shivering
  - Hyperthermia
  - Anemia

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Factors that Decrease O_2ER

- Increased cardiac output
- Skeletal muscle relaxation
  - Drug induced
- Peripheral shunting (e.g., sepsis)

Factors that Decrease O_2ER

- Certain poisons
  - Cyanide
- Hypothermia
- Increased Hb
- Increased arterial oxygenation (PaO_2)

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Mixed Venous Oxygen Saturation (SvO_2)

- Changes in the SvO_2 can be used to detect changes in the:
  - $C(a\text{-}v)O_2$
  - VO_2
  - O_2ER

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Factors that Decrease the SvO_2

- Decreased cardiac output
- Exercise
- Seizures
- Shivering
- Hyperthermia

Factors that Increase the SvO_2

- Increased cardiac output
- Skeletal muscle relaxation
  - Drug induced
- Peripheral shunting
  - Sepsis

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Factors that Increase the SvO_2

- Certain poisons
  - Cyanide
- Hypothermia

Oxygen Transport Calculations

Table 6-10

Clinical Factors	DO_2	VO_2	$C(a-v)O_2$	O_2ER	SvO_2
↑ O_2 loading	↑	Same	Same	↓	↑
↑ Hb					
↑ PaO_2					
↓ $PaCO_2$					
↑ pH					
↑ Temperature					

Oxygen Transport Calculations

Table 6-10

Clinical Factors	DO_2	VO_2	$C(a\text{-}v)O_2$	O_2ER	SvO_2
↓ O_2 loading	↓	Same	Same	↑	↓
↓ Hb					
↓ $PaCO_2$					
↓ pH					
↓ PaO_2					
Anemia					
↓ Temperature					

Oxygen Transport Calculations

Table 6-10

Clinical Factors	DO_2	VO_2	$C(a\text{-}v)O_2$	O_2ER	SvO_2
↑ Metabolism	Same	↑	↑	↑	↓
Exercise					
Seizures					
Hyperthermia					
Shivering					

THOMSON DELMAR LEARNING

Oxygen Transport Calculations

Table 6-10

Clinical Factors	DO_2	VO_2	$C(a-v)O_2$	O_2ER	SvO_2
↓ Metabolism	Same	↓	↓	↓	↑
Hypothermia					
Skeletal muscle relaxation					

THOMSON DELMAR LEARNING

Oxygen Transport Calculations

Table 6-10

Clinical Factors	DO_2	VO_2	$C(a\text{-}v)O_2$	O_2ER	SvO_2
↓ Cardiac Output	↓	Same	↑	↑	↓

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Oxygen Transport Calculations

Table 6-10

Clinical Factors	DO_2	VO_2	$C(a\text{-}v)O_2$	O_2ER	SvO_2
↑ Cardiac Output	↑	Same	↓	↓	↑

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Oxygen Transport Calculations

Table 6-10

Clinical Factors	DO_2	VO_2	$C(a\text{-}v)O_2$	O_2ER	SvO_2
Peripheral shunting	Same	↓	↓	↓	↑

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Oxygen Transport Calculations

Table 6-10

Clinical Factors	DO_2	VO_2	$C(a\text{-}v)O_2$	O_2ER	SvO_2
Certain Poisons	Same	↓	↓	↓	↑

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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

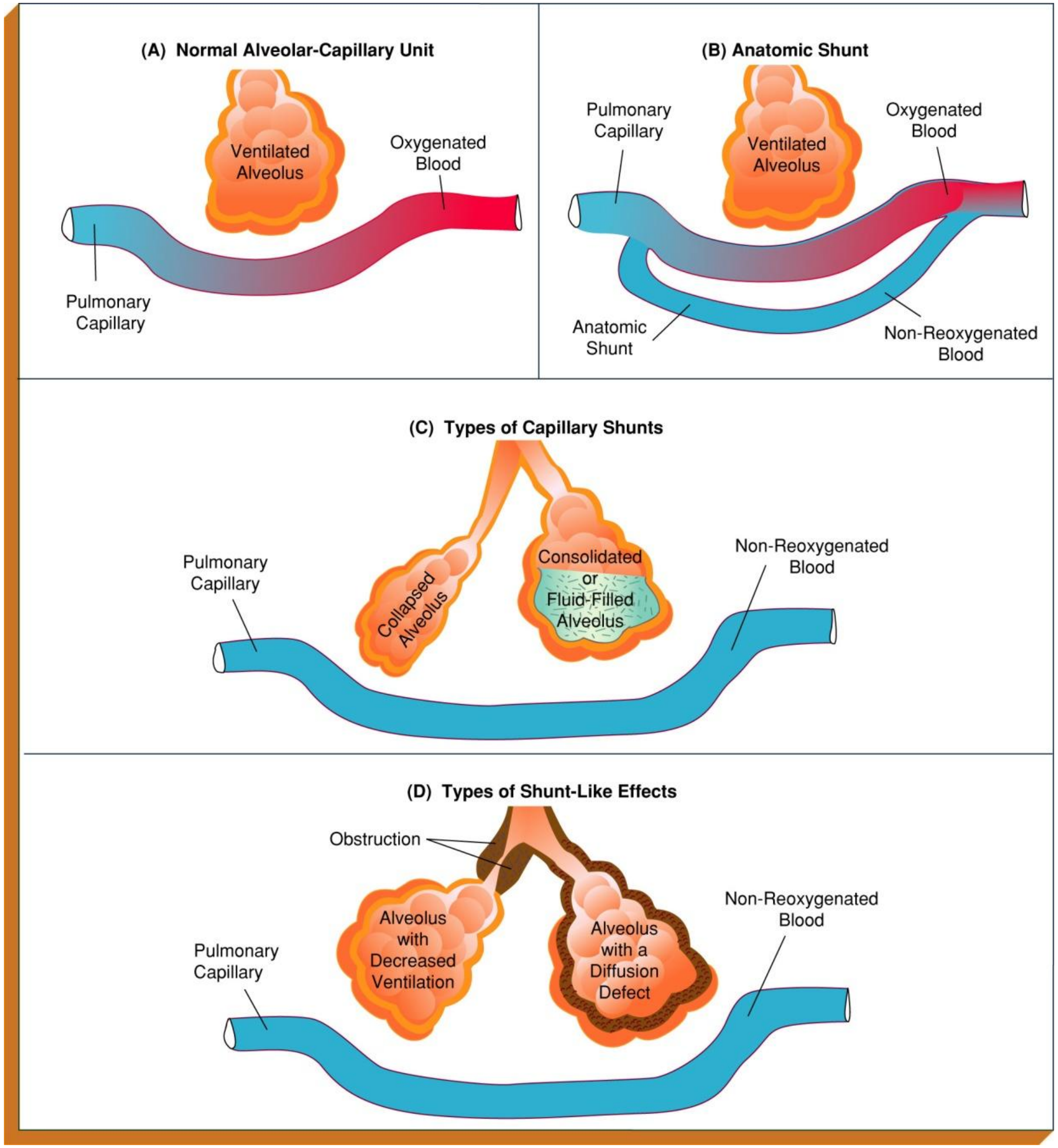

Fig. 6-12. Pulmonary shunting.

Common Causes of Absolute Shunting

- Congenital heart disease
- Intrapulmonary fistula
- Vascular lung tumors

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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

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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 Admixture

- 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

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Venous Admixture

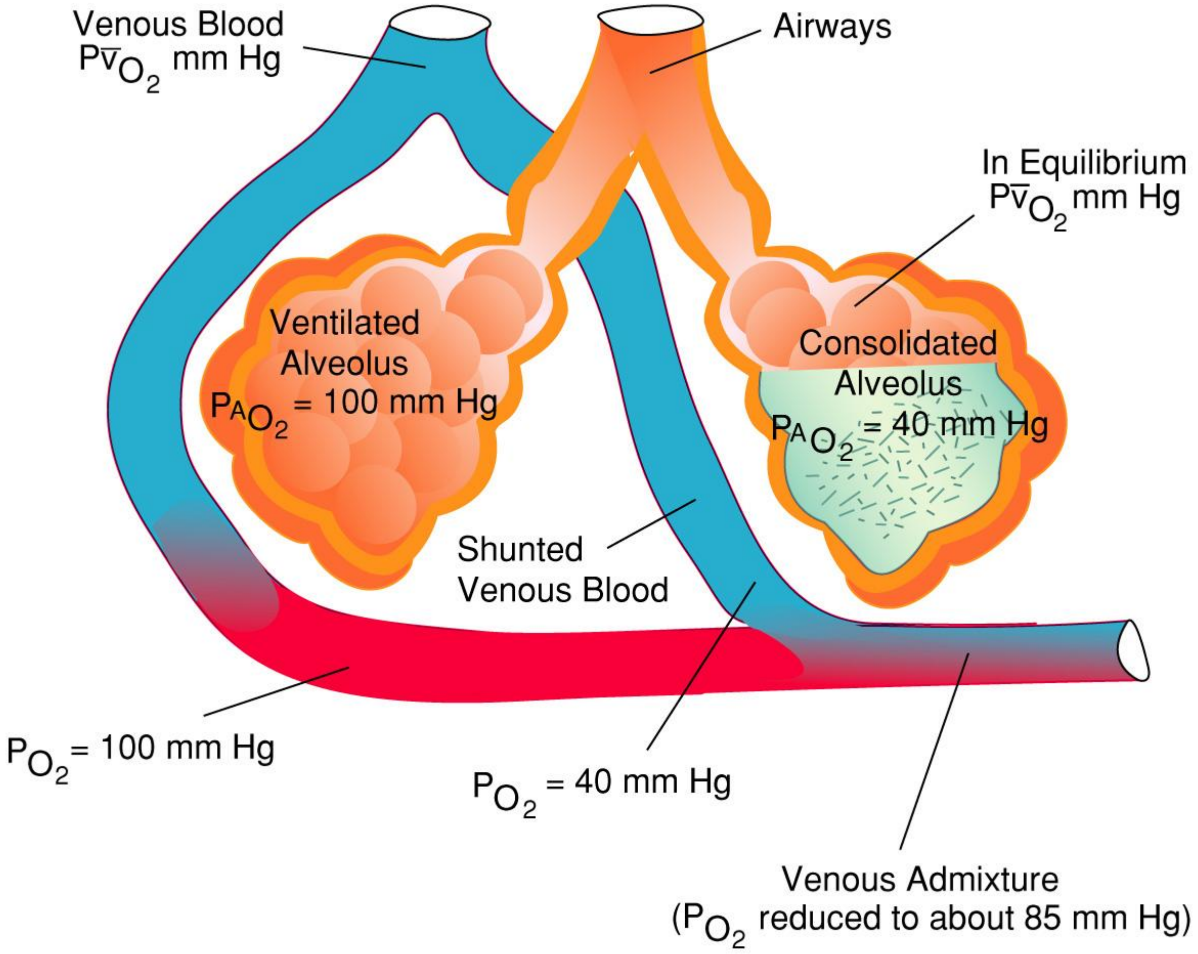

Fig. 6-13. Venous admixture occurs when reoxygenated blood mixes with non-reoxygenated blood.

Pulmonary Equation

$$\frac{Q_s}{Q_T} = \frac{CcO_2 - CaO}{CcO_2 - CvO_2}$$

Shunt Equation Clinical Information Needed

- PB
- PaO_2
- $PaCO_2$
- PvO_2
- Hb
- PAO_2
- FIO_2

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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:

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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%)

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Case Study: Motorcycle Accident Victim

- With this information, the patient's PAO_2, CcO_2, CaO_2, and CvO_2 can now be calculated

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Case Study: Motorcycle Accident Victim

1. $PAO_2 = (PB - PH_2O)\ FIO_2 - PaCO_2\ (1.25)$

$$= (750 - 47)\ 0.70 - 43\ (1.25)$$

$$= (703)\ 0.70 - 53.75$$

$$= 492.1 - 53.75$$

$$= 438.35 \text{ mm Hg}$$

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Case Study: Motorcycle Accident Victim

2. CcO_2 = (Hb x 1.34) + (PAO_2 x 0.003)

= (13 x 1.34) + (438.35 x 0.003)

= 17.42 + 1.315

= 18.735 (vol% O_2)

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Case Study: Motorcycle Accident Victim

3. $CaO_2 = (Hb \times 1.34 \times SaO_2) + (PaO_2 \times 0.003)$

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

$= 14.807 + 0.15$

$= 14.95$ (vol% O_2)

Case Study: Motorcycle Accident Victim

4. $CaO_2 = (Hb \times 1.34 \times SvO_2) + (PvO_2 \times 0.003)$

$= (13 \times 1.34 \times .65) + (37 \times 0.003)$

$= 11.323 + 0.111$

$= 11.434$ (vol% O_2)

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Case Study: Motorcycle Accident Victim

- Based on the previous calculation the patient's degree of pulmonary shunting can now be calculated:

$$\frac{Q_S}{Q_T} = \frac{CcO_2 - CaO_2}{CcO_2 - CvO_2}$$

$$= \frac{18.735 - 14.957}{18.375 - 11.434}$$

$$= \frac{3.778}{7.301}$$

$$= 0.515$$

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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

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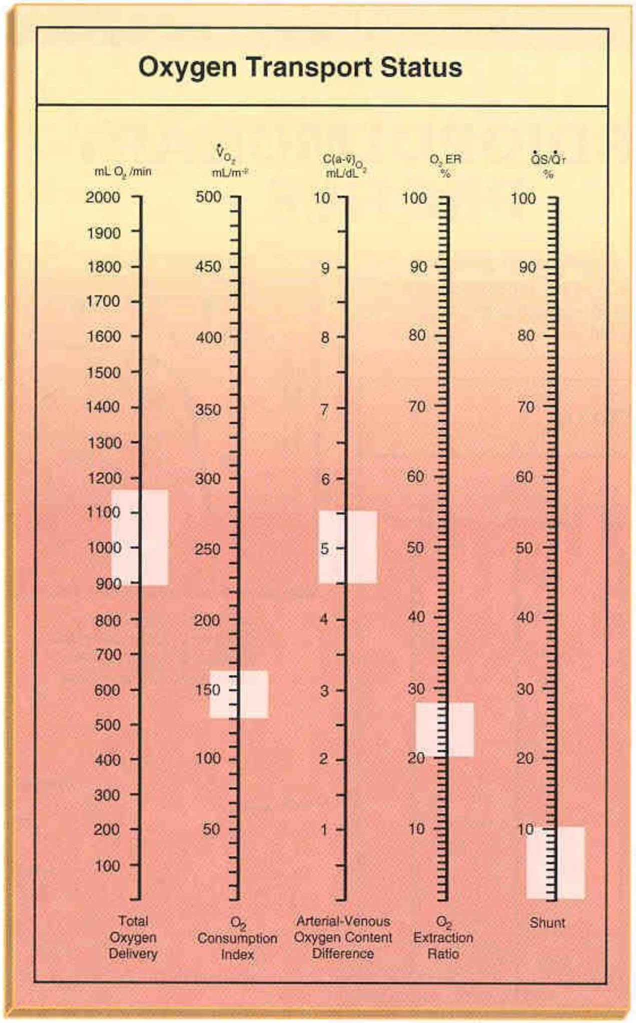
Appendix V



Blood Gas Values

pH ______

Pa_{CO_2} ______

HCO_3^- ______

Pa_{O_2} ______ $P\bar{v}_{O_2}$ ______

Sa_{O_2} ______ % $S\bar{v}_{O_2}$ ______ %

FI_{O_2} ______ Hb ______

Mode(s) of Ventilatory

Support: ______

Shaded areas represent normal ranges.

Patient's Name ______

Date ______

Time ______

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HYPOXIA

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HYPOXEMIA VERSUS HYPOXIA

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Hypoxemia

- Abnormally low arterial oxygen tension (PaO_2)
- Frequently associated with hypoxia
  - Which is an inadequate level of tissue oxygenation

Hypoxemia Classifications

Classifications	PaO_2 (rule of thumb)
Normal	80-100 mm Hg
Mild hypoxemia	60-80 mm Hg
Moderate hypoxemia	40-60 mm Hg
Severe hypoxemia	<40 mm Hg

Hypoxia

- Low or inadequate oxygen for cellular metabolism

Hypoxia

- 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

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Types of Hypoxia

- Anemic hypoxia
  - 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

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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

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Types of Hypoxia

- Circulatory hypoxia
  - Common causes
    - Slow or stagnant (pooling) peripheral blood flow
    - Arterial-venous shunts

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Types of Hypoxia

- Histotoxic hypoxia
  - Impaired ability of the tissue cells to metabolize oxygen
  - Common cause
    - Cyanide poisoning

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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

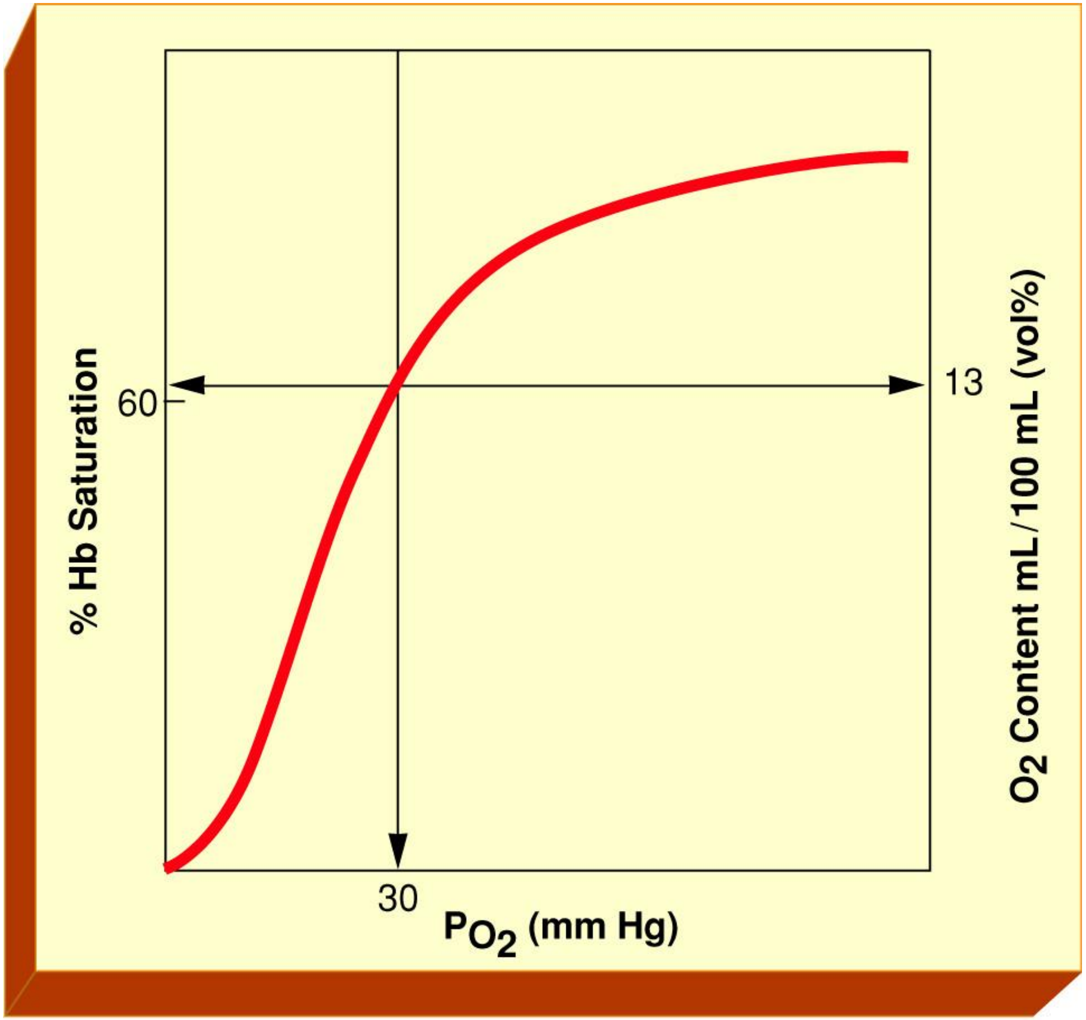

Fig. 6-14. Cyanosis may appear whenever the blood contains at least 5 g% of reduced hemoglobin.

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

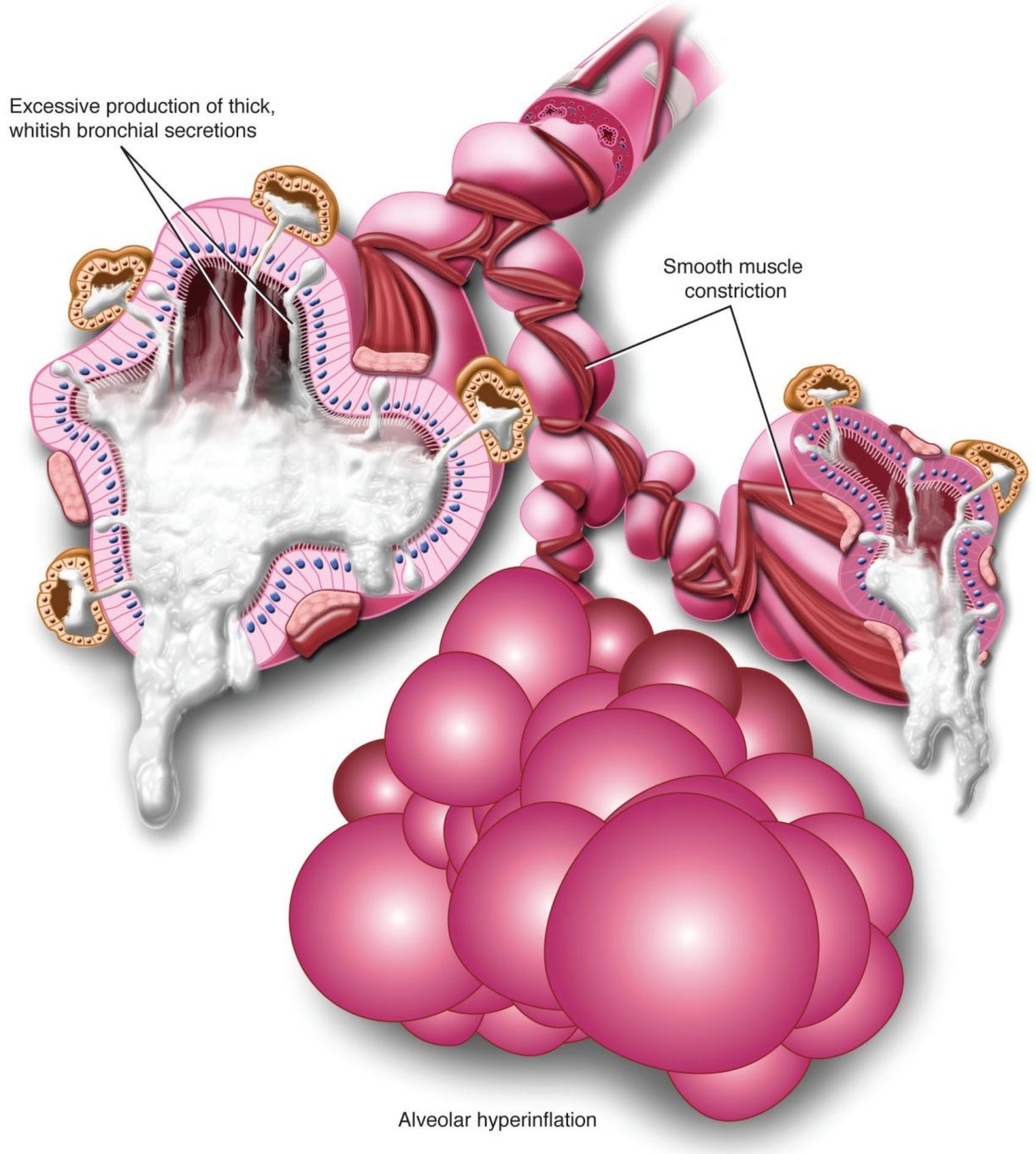

Fig. 6-15. Asthma. Pathology includes (1) bronchial smooth muscle constriction, (2) inflammation and excessive production of thick, whitish bronchial secretions, and (3) alveolar hyperinflation.

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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)?