THE RESPIRATORY SYSTEM

The Physiologic Basis of Surgery

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ระบบหายใจ

มีหน้าที่หลักใน การหายใจ (Respiration)

THE PROCESS BY WHICH THE BODY TAKES IN AND USES O₂ AND REMOVES CO₂

\[ \text{O}_2 + \text{FOOD} \rightarrow \text{ENERGY} + \text{CO}_2 \]
ระบบหายใจ

การหายใจเกิดขึ้นที่ 2 ระดับคือ

- External respiration
- Internal respiration หรือ cellular respiration
External Respiration
External Respiration

Diagram showing the process of external respiration, including pulmonary capillaries, pulmonary veins, systemic veins, heart, systemic arteries, systemic capillaries, and cells in tissues throughout the body. The diagram illustrates the flow of oxygenated and deoxygenated blood.
Internal Respiration

- Cells in tissues throughout the body
- Blood vessel
- Internal respiration

Cell:
- Mitochondria
- ATP

Color codes:
- Red = Oxygenated blood
- Blue = Deoxygenated blood

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- Pulmonary ventilation
- Diffusion
- Transportation
- Diffusion
ระบบหายใจ

สรุปกระบวนการทำงานของระบบหายใจ

• Pulmonary ventilation
• Diffusion
• Transportation
• Cellular respiration
Scope

- Structure and Function
- Ventilation
- Perfusion
- Ventilation perfusion relationship
- Mechanics of breathing
- Transportation
- Diffusion
- Control of breathing
หน้าที่อื่น ๆ ของระบบหายใจ

• **BEHAVIORAL**
  • talking, laughing, singing, reading

• **DEFENSE**
  • humidification, particle expulsion (coughing, sneezing), particle trapping (clots), immunoglobulins from tonsils and adenoids, a-1 antitrypsin, lysozyme, interferon, complement system

• **SECRETIONS**
  • mucus (goblet cells, mucus glands)
• METABOLIC
  • forms angiotensin II, prostacyclin, bradykinin, serotonin and histamine

• ACID - BASE BALANCE
  • changes in ventilation; e.g., acute acidosis of exercise

• MISCELLANEOUS
  • lose heat and water, liquid reservoir for blood, force generation for lifting, vomiting, defaecation and childbirth
Structure and Function
Lung and Thoracic Cavity

STRUCTURE OF THE LUNGS AND THORACIC CAVITY

(a) The respiratory system
- Tongue
- Nasal cavity
- Pharynx
- Vocal cords
- Esophagus
- Larynx
- Trachea
- Right lung
- Left lung
- Right bronchus
- Left bronchus
- Diaphragm

(b) Muscles used for ventilation
- Sternocleido-mastoids
- Scalenues
- External intercostals
- Diaphragm
- Internal intercostals
- Abdominal muscles

Muscles of inspiration
Muscles of expiration
Airways

• **Conducting Zone**
  • Trachea --> Terminal bronchioles

• **Respiratory Zone**
  • Respiratory Bronchiole --> Alveolar Ducts --> Alveoli
# Conducting Zone

<table>
<thead>
<tr>
<th>Structure</th>
<th>Inner diameter (mm)</th>
<th>Cilia</th>
<th>Goblet cells</th>
<th>Cartilage</th>
<th>Smooth muscle</th>
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<tbody>
<tr>
<td>Larynx</td>
<td>35–45</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>0</td>
</tr>
<tr>
<td>Trachea</td>
<td>20–25</td>
<td>+++</td>
<td>+++</td>
<td>+++ (C-shaped)</td>
<td>+</td>
</tr>
<tr>
<td>Primary bronchi</td>
<td>12–16</td>
<td>+++</td>
<td>++</td>
<td>+++ (rings)</td>
<td>++</td>
</tr>
<tr>
<td>Secondary bronchi</td>
<td>10–12</td>
<td>+++</td>
<td>++</td>
<td>+++ (plates)</td>
<td>++</td>
</tr>
<tr>
<td>Tertiary bronchi</td>
<td>8–10</td>
<td>+++</td>
<td>++</td>
<td>++ (plates)</td>
<td>++</td>
</tr>
<tr>
<td>Smaller bronchi</td>
<td>1–8</td>
<td>+++</td>
<td>+</td>
<td>+ (plates)</td>
<td>++</td>
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<tr>
<td>Bronchioles</td>
<td>0.5–1</td>
<td>++</td>
<td>+</td>
<td>0</td>
<td>+++</td>
</tr>
<tr>
<td>Terminole bronchioles</td>
<td>&lt; 0.5</td>
<td>++</td>
<td>0</td>
<td>0</td>
<td>+++</td>
</tr>
</tbody>
</table>
Conducting Zone

- **Air transport**
  - Anatomical dead space (150 ml.)
  - Humidification and temperature regulation (*conditioning* the air)
  - *Filtration* and removal of particles
Respiratory Zone

- Alveolar duct
- Alveoli
- Respiratory bronchioles
- Terminal bronchiole
- Alveolar sac
- Alveolar duct
- Alveolus
Respiratory Zone

- **Gas exchange**
- **Volume 3000 ml.**
Respiratory Zone

- Airway Branching
Respiratory Membrane

• This air-blood barrier is composed of:
  • Alveolar and capillary walls
  • Their fused basal laminas

• Alveolar walls:
  • Are a single layer of type I epithelial cells
  • Permit gas exchange by simple diffusion
  • Secrete angiotensin converting enzyme (ACE)

• Type II cells secrete surfactant
Respiratory Membrane

- Smooth muscle
- Capillaries
- Alveolus
- Elastic fibers
Respiratory Membrane

- Type II (surfactant-secreting) cell
- Type I cell of alveolar wall
- Epithelial cell nucleus
- Endothelial cell nucleus
- Capillary
- Alveoli (gas-filled airspaces)
- Red blood cell
- Alveolar pores
- Alveolar epithelium
- Fused basal lamina of the alveolar epithelium and the capillary endothelium
- Capillary endothelium

Oxygen (O2) and Carbon Dioxide (CO2) exchange between the blood and the lungs.
Blood Supply to Lungs

2 circulations

• Pulmonary circulation
• Bronchial circulation
Pulmonary Circulation

- **Pulmonary arteries** – supply systemic venous blood to be oxygenated
  - Branch profusely, along with bronchi
  - Ultimately feed into the pulmonary capillary network surrounding the alveoli

- **Pulmonary veins** – carry oxygenated blood from respiratory zones to the heart
Bronchial Circulation

- **Bronchial arteries** – provide systemic blood to the lung tissue
  - Arise from aorta and enter the lungs at the hilus
  - Supply all lung tissue except the alveoli
- **Bronchial veins** anastomose with pulmonary veins
- Anatomical shunt
Inspiration

- Diaphragm and external intercostal muscles contract
- The size of the thoracic cavity increases
- External air is pulled into the lungs due to an increase in intrapulmonary volume
  - Causes pressure to be less than atmospheric, creating a vacuum, leading to air being sucked into the lungs
  - Air flows until intrapulmonary pressure equals atmospheric pressure
Inspiration

Changes in anterior-posterior and superior-inferior dimensions

Ribs elevated as external intercostals contract

External intercostal muscles

Diaphragm moves inferiorly during contraction

Changes in lateral dimensions

Full inspiration
Exhalation

• Largely a passive process which depends on natural lung elasticity
• As muscles relax, rib cage compresses and lungs recoil to original shapes and air is pushed out of the lungs
• *Forced expiration* can occur mostly by contracting internal intercostal muscles to depress the rib cage (narrowing, disease)
• Abdominal muscle
Exhalation

(b) Expiration

- Ribs depressed as external intercostals relax
- External intercostal muscles
- Diaphragm moves superiorly as it relaxes
VENTILATION

How Gas Gets to the Alveoli
Lung Volumes and Capacities

Maximum possible inspiration

Lung volume (mL)

- Inspiratory reserve volume
- Expiratory reserve volume
- Residual volume
- Functional residual capacity
- Vital capacity
- Inspiratory capacity
- Total lung capacity
- Tidal volume

Maximum voluntary expiration
Lung Volumes

- **Tidal volume** ($V_T$) – air that moves into and out of the lungs with each breath
- **Inspiratory reserve volume** (IRV) – air that can be inspired forcibly beyond the tidal volume (2100–3200 ml)
- **Expiratory reserve volume** (ERV) – air that can be evacuated from the lungs after a tidal expiration (1000–1200 ml)
- **Residual volume** (RV) – air left in the lungs after strenuous expiration (1200 ml)
Lung Capacities

- **Inspiratory capacity (IC)** – total amount of air that can be inspired after a tidal expiration (IRV + TV)
- **Functional residual capacity (FRC)** – amount of air remaining in the lungs after a tidal expiration (RV + ERV)
- **Vital capacity (VC)** – the total amount of exchangeable air (TV + IRV + ERV)
- **Total lung capacity (TLC)** – sum of all lung volumes (approximately 6000 ml in males)
FRC

Graph showing lung volume percentage (Lung Volume) over age (Age) with markers for FRC, Closing Volume, and Tidal Volume.
• Anatomical Dead Space
• Alveolar Dead Space
• Physiological Dead Space
Anatomical Dead Space

- Volume of the conducting respiratory passages (150 ml)
  - $V_T = 500$ ml
  - Anatomical dead space = 150 ml
  - $V_D/V_T = 150/500 = 0.3$ (0.25-0.35)
Alveolar Dead Space

- Volume of air in the lung that is not involved in gas exchange
- Air in the lung that has not received blood
- Air in the lung that has received less blood
- Air in the lung that has received less blood due to obstruction
Physiological Dead Space

Physiological $V_D = \text{Alveolar } V_D + \text{Anatomical } V_D$

• Normal lung
  • Physiological $V_D = \text{Anatomical } V_D$
Physiological Dead Space

\[
\frac{V_D}{V_T} = \frac{\text{PaCO}_2 - \text{PECO}_2}{\text{PaCO}_2}
\]

Normal ratio of \(V_D/V_T = 0.2-0.35\) during resting breathing
Ventilation

การเข้าออกของอากาศในระบบทางเดินหายใจ

• Pulmonary ventilation
• Alveolar ventilation
Pulmonary Ventilation

ปริมาตรอากาศที่หายใจเข้าออกปกติใน 1 นาที

\[ V_T = 500 \text{ml} \quad \text{RR}= 15/\text{min} \]

\[ V_E = V_T \times \text{RR} \]

\[ = 500 \times 15 \]

\[ = 7500 \text{ ml/min} \]
Alveolar Ventilation

ปริมาตรอากาศที่ผ่านเข้าไปใน respiratory zone ต่อ 1 นาที เป็นส่วนหนึ่งของ pulmonary ventilation ที่มีการแลกเปลี่ยนแก๊ส

<table>
<thead>
<tr>
<th>( \dot{V}_A )</th>
<th>=</th>
<th>frequency</th>
<th>( X )</th>
<th>( V_T - V_D )</th>
</tr>
</thead>
<tbody>
<tr>
<td>(ml/min)</td>
<td>(breaths/min)</td>
<td></td>
<td>(ml/breath)</td>
<td></td>
</tr>
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</table>
Alveolar Ventilation

<table>
<thead>
<tr>
<th>Lower $\dot{V}_D/\dot{V}_T$</th>
<th>Normal $\dot{V}_D/\dot{V}_T$</th>
<th>Higher $\dot{V}_D/\dot{V}_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>0.3 - 0.4</td>
<td>1.0</td>
</tr>
<tr>
<td>$\uparrow \dot{V}_A$</td>
<td>$\downarrow \dot{V}_A$</td>
<td>$\uparrow \dot{V}_D$</td>
</tr>
</tbody>
</table>

Minute Volume = tidal volume $\times$ rate

- **A**: $\dot{V}_D = 4800$ ml, $\dot{V}_A = 3200$ ml
- **B**: $\dot{V}_D = 2400$ ml, $\dot{V}_A = 5600$ ml
- **C**: $\dot{V}_D = 1200$ ml, $\dot{V}_A = 6800$ ml

30 seconds
No gas exchange occurs in the anatomic dead space

\[ \text{P}_a\text{CO}_2 \propto \frac{\dot{V}_{E\text{CO}_2}}{\dot{V}_A} \]
Pressures within pulmonary blood vessels

- The walls of the pulmonary artery and its branch are remarkably thin and contain little smooth muscle.
- The systemic circulation where the arteries have thick wall and its have abundant smooth muscle.
Pulmonary Circulation

• Low-pressure, low resistance system
• Highly distensible
• Contain little smooth muscle
• Some bronchial venous blood drain directly into pulmonary veins
  • $\text{PaO}_2 < \text{PAO}_2$
Clinical Measurement of Pulmonary Blood Pressure and Flow
Clinical Measurement of Pulmonary Blood Pressure and Flow
Pulmonary vascular resistance

- Vascular resistance of systemic blood vessels = $\Delta P/\text{flow}$
- Pulmonary blood flow (CO) is about 6 liters/min
- $PVR = (15-5)/6 = 1.7 \text{ mmHg/liter/min.}$
Pulmonary Vascular Resistance (PVR)

\[ PVR = \frac{MPAP - PAWP}{CO} \]
Factors Affecting PVR

• Passive
• Active
Active control of the circulation

- Hypoxic pulmonary vasoconstriction
  - Active response occurs when the Po$_2$ of alveolar gas is reduced.
- Endothelium-derived vasoactive substances
  - NO = endothelium-derived relaxing factor for blood vessels
  - Endothelin = potent vasoconstrictor peptide
Active control of the circulation

• A low blood pH cause vasoconstriction, especially when alveolar hypoxia is present
• An increase in sympathetic outflow causing stiffening of the walls of the pulmonary arteries and vasoconstriction.
Passive control of the circulation

Recruitment (opening of previously closed vessels) and distension (increase in caliber of vessels). These are the two mechanisms for the decrease in pulmonary vascular resistance that occurs as vascular pressures are raised.
Passive control of the circulation

Fall in pulmonary vascular resistance as the pulmonary arterial or venous pressure is raised. When the arterial pressure was changed, the venous pressure was held constant at 12 cm water, and when the venous pressure was changed, the arterial pressure was held at 37 cm water. (Data from an excised dog lung preparation).
Passive control of the circulation

“Alveolar” and “extra-alveolar” vessels. The first are mainly the capillaries and are exposed to alveolar pressure. The second are pulled open by the radial traction of the surrounding lung parenchyma, and the effective pressure around them is therefore lower than alveolar pressure.
Passive control of the circulation

Effect of lung volume on pulmonary vascular resistance when the transmural pressure of the capillaries is held constant. At low lung volumes, resistance is high because the extra-alveolar vessels become narrow. At high volumes, the capillaries are stretched and their caliber is reduced. (Data from a dog lobe preparation.)
Passive control of the circulation

• The important determinant of PVR is *lung volume*.
• They have high resistance when lung volume is low.
• The caliber of capillaries is reduced at large lung volumes because of stretching of the alveolar walls.
Pulmonary vascular resistance

• Role of smooth muscle in determining the caliber of the extra-alveolar vessels.
• The drugs that cause vasoconstriction include serotonin, histamine and norepinephrine --> $\uparrow$ PVR
• The drugs that can relax smooth muscle in the pulmonary circulation include acetylcholine and isoproterenol --> $\downarrow$ PVR
Ventilation-perfusion Relationships
การกระจายของเลือดในปอด
Zone 1 $P_A > P_a > P_V$
Zone 2 $P_a > P_A > P_V$
Zone 3 $P_a > P_V > P_A$
การกระจายของอากาศในปอด
การกระจายของอากาศในปอด
ความสัมพันธ์ระหว่างการกระจายของเลือดและอากาศในปอด
Oxygen transport from air to tissues

- Level of $P_{A}O_2$ is determined by balance of:
  - The rate of removal of $O_2$ by the blood
  - The rate of replenishment of $O_2$ by alveolar ventilation
ความสัมพันธ์ระหว่างการกระจายของเลือดและอากาศในปอด
ความสัมพันธ์ระหว่างการกระจายของเลือดและอากาศในปอด
ความสัมพันธ์ระหว่างการกระจายของเลือดและอากาศในปอด
Alveolar-Arterial Oxygen pressure Difference \((P_{(A-a)O_2})\)

**Alveolar gas equation**

\[
P_{A\text{O}_2} = P_{\text{iO}_2} - \frac{P_{\text{ACO}_2}}{R} + F
\]

\[
= \text{FiO}_2 (760-P_{\text{H}_2\text{O}}) - \frac{\text{PaCO}_2}{R}
\]
Is PaCO₂ increased?

- Yes
  - Hypoventilation
    - Is PAO₂ - PaO₂ increased?
      - No: Hypoventilation alone
        1. ↓Respiratory drive
        2. Neuromuscular disease
      - Yes: Hypoventilation plus another mechanism

- No
  - Is PAO₂ - PaO₂ increased?
    - Yes: Is low P O₂ correctable with O₂?
      - No: ↓Inspired P O₂
        1. High altitude
        2. ↓FiO₂
      - Yes: V/Q mismatch
        1. Airways disease (asthma, COPD)
        2. Interstitial lung disease
        3. Alveolar disease
        4. Pulmonary vascular disease
    - No: Shunt
      1. Alveolar collapse (atelectasis)
      2. Intraalveolar filling (pneumonia, pulmonary edema)
      3. Intracardiac shunt
      4. Vascular shunt within lungs
Abnormal Gas Exchange

- Hypoventilation
- Absolute shunt
- \( V/Q \) mismatch
# Abnormal Gas Exchange

<table>
<thead>
<tr>
<th>Cause</th>
<th>P(A-a)O$_2$</th>
<th>Response to O$_2$</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypoventilation</td>
<td>Normal</td>
<td>Good</td>
<td>Drug overdose</td>
</tr>
<tr>
<td>Shunt</td>
<td>Increased</td>
<td>Poor</td>
<td>Atelectasis, Pneumonia</td>
</tr>
<tr>
<td>V/Q mismatch</td>
<td>Increased</td>
<td>Good</td>
<td>Partial AW obstruction</td>
</tr>
</tbody>
</table>
Hypoventilation

- If alveolar ventilation is abnormally low
  - The alveolar Po$_2$ fall, the Pco$_2$ rises
- Cause of hypoventilation
  - Drugs which depress the central drive to the respiratory muscles
  - Damage to the chest wall
  - Paralysis of respiratory muscles
  - High resistance to breathing
Hypoventilation

• The relationship between alveolar ventilation and $P_{CO_2}$

• $P_A CO_2 = \dot{V} CO_2 / \dot{V}_A * K$
Hypoventilation

• The relationship between the fall in Po$_2$ and the rise in Pco$_2$ can be calculated from

Alveolar gas equation

$$P_{AO2} = P_{1O2} - \frac{P_{ACO2}}{R} + F$$

$F$ = small collection factor $\sim$ 2 mmHg

$R$ = respiratory exchange ratio $\sim$ 0.8
Absolute Shunt

- Anatomical shunt
  - Normal เช่น bronchial systemic vein
  - Abnormal เช่น VSD
- Physiologic or intrapulmonary shunt
Clinical measurement of Shunt

- $P(A-a)O_2$
- $PaO_2 / PAO_2$
- $PaO_2 /FiO_2$
Shunt Equation

\[ \frac{\dot{Q}_S}{\dot{Q}_T} = \frac{Cc'O_2 - CaO_2}{Cc'O_2 - C\tilde{v}O_2} \]
### Clinical Significance of Shunt

<table>
<thead>
<tr>
<th>Shunt Fraction (%)</th>
<th>Clinical Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10%</td>
<td>Clinical compatible with normal lung</td>
</tr>
<tr>
<td>10-19%</td>
<td>Intrapulmonary abnormality</td>
</tr>
<tr>
<td>20-29%</td>
<td>Significant abnormality; requires ventilatory support with PEEP</td>
</tr>
<tr>
<td>&gt;30%</td>
<td>Severe disease</td>
</tr>
</tbody>
</table>
การขนส่งแก๊สในเลือด
(Gas Transport between The Lungs and Body Tissue)
การขนส่งออกซิเจน

1. ออกซิเจนที่ละลายในพลasma (dissolve oxygen)

   \[ = O_2 \text{ solubility coefficient} \times So_2 \]

   \[ = 0.003 \times PO_2 \]

   \[ = 0.003 \times 100 \]

   \[ = 0.3 \text{ มล. } O_2 \text{ ต่่อเล็กที่ } 100 \text{ มอล.} \]
การขนส่งออกซิเจน

2. ออกซิเจนที่รวมกับปิย์โมโปรตีน (oxyhemoglobin)
   \[ = O_2 \text{ capacity of Hb} \times \text{Hb} \times \text{SO}_2 \]
   \[ = 1.34 \times 15 \times (98/100) \]
   \[ = 19.7 \text{ มล./เลือด 100 มล.} \]
การขนส่งออกซิเจน

• Oxygen Content (CaO₂)
  • ออกซิเจนที่รวมกับฮีโมโกลบิน
  • ออกซิเจนที่ละลายในพลาสมา
  • \(19.7 + 0.3 = 20\) มล. ต่อ เลือด 100 มล.
OXYGEN DELIVERY

\[ \text{Do}_2 = \dot{Q} \times \text{Ca}_{O2} \]

- \( \dot{Q} \) = Cardiac output = 5000 ml/min
- \( \text{Ca}_{O2} \) = Oxygen Content = 20 ml/100ml of blood
- \( \text{Do}_2 \) = Oxygen Delivery = 1000 ml/min
OXYGEN CONSUMPTION

\[ \dot{V}_{o_2} = Q \cdot (C_{a_O2} - C_{\dot{v}_{O2}}) \]

= 250 ml/min

\[ \dot{Q} = \dot{V}_{o_2} / (C_{a_O2} - C_{\dot{v}_{O2}}) \]

Fick principle
Oxygen Extract Ratio

• สัดส่วนระหว่างปริมาณของ O₂ ที่เซลล์รับไปใช้ใน 1 นาที ต่อปริมาณของ O₂ ในเลือดแดง

\[
O₂ \text{ Extract Ratio} = \frac{(Ca_{O₂} - C_{v\ O₂})}{Ca_{O₂}}
\]

• ในภาวะปกติ มีค่าเท่ากับ 20-15/20 = 0.25
Critical Illness

\[ \downarrow D_02 \iff \dot{V}_o2 \]

\[ \dot{V}_o2 = \downarrow Q \cdot \uparrow (C_{a_o2} - \downarrow C\dot{v}_{o2}) \]

- Extraction Fraction

\[ EF = (C_{a_o2} - C\dot{v}_{o2}) / C_{a_o2} \]
Supply dependence of Oxygen consumption

Extraction limit for maintaining aerobic metabolism
$\text{EFc} = 0.67$

**Anaerobic metabolism**

$\uparrow$ Lactic acid production  
$\uparrow$ L:P ratio  
$\downarrow$ ATP
Pathologic Supply Dependence of \( \dot{V}O_2 \)
O$_2$ Extraction Defect

$\downarrow$ Do$_2$ $\rightarrow$ $\uparrow$ EFc < 0.67

Sepsis

Impair regulation of $\dot{Q}$ / $\dot{V}$o$_2$ variance
- among various organ
- within individual organ
Adequate aerobic metabolism

\[ \downarrow \dot{V}O_2 \quad \uparrow D O_2 \]
• $\uparrow V_{O_2}$
  - Febrile pt. with burn, trauma, sepsis
  - Acute respiratory failure with $\uparrow$ WOB

• $\downarrow V_{O_2}$
  - Muscle relaxation
  - Artificial respiration
  - Cooling
Lactic acidosis in high $\text{Do}_2$

- Anaerobic Metabolism

- Hypovolemic, Cardiogenic shock $\rightarrow \uparrow \uparrow \text{L:P ratio}$

- Septic shock $\rightarrow \uparrow \uparrow \text{Pyruvate}$
The Oxygen Dissociation Curve

O2 Cont.  Sat. (%)  P O2 (mm hg)
0          0        27
5          25       40
10         50       55
15         75       100
20         100      650

H+ CO2 T
2,3 DPG

H+ CO2 T
2,3 DPG

0.3  2.0
\[
\text{Ca}_\text{O}_2 = 1.34 \times \text{Hb} \times \text{SO}_2 + 0.003 \times \text{PaO}_2
\]

In normal pH, PaO\textsubscript{2}, Temp

<table>
<thead>
<tr>
<th>O\textsubscript{2} sat</th>
<th>PaO\textsubscript{2}</th>
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<tbody>
<tr>
<td>50%</td>
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<tr>
<td>75%</td>
<td>40</td>
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<tr>
<td>90%</td>
<td>55</td>
</tr>
<tr>
<td>100%</td>
<td>&gt;100</td>
</tr>
</tbody>
</table>

\(P_{50}\) \hspace{1cm} \(P_{V\text{O}_2}\)
\[ \text{CaO}_2 = 1.34 \times \text{Hb} \times \text{O}_2\text{Sat} + 0.003 \times \text{PaO}_2 \]

At \( \text{O}_2\text{Sat} = 100\% \)

- Hb 1 gm \( \text{O}_2 \) 1.34 ml
- Hb 15 g/dl \( \text{O}_2 \) 20 ml /100 ml of blood

\( \text{O}_2 \) solubility in plasma = 0.003 ml/mmHg /100 ml of blood

- \( \text{PaO}_2 \) 100 mmHg \( \text{CaO}_2 \) 0.3 ml /100 ml of blood
- \( \text{PaO}_2 \) 650 mmHg \( \text{CaO}_2 \) 2.0 ml /100 ml of blood
The diagram illustrates the relationship between oxygen content (O₂ Cont.) and saturation (Sat.) in the context of oxygen affinity. The graph shows how various factors, such as pH (H⁺), carbon dioxide (CO₂), and 2,3-diphosphoglycerate (2,3 DPG), affect the oxygen affinity (O₂ affinity). An increase in pH or 2,3 DPG leads to a decrease in O₂ affinity, as indicated by the downward arrow. Conversely, an increase in carbon dioxide (CO₂) results in an increase in O₂ affinity, as shown by the upward arrow. The graph also includes specific points, such as 0.3 and 2.0, which likely represent concentrations or other relevant parameters. The x-axis represents partial pressure of oxygen (P O₂) in millimeters of mercury (mm Hg), ranging from 27 to 650. The y-axis shows oxygen content (O₂ Cont.) and saturation (Sat.) values from 0 to 100, indicating the percentage of oxygen saturation in the blood.
Anemia

CO Poisoning

O₂ Content (ml\%)

P O₂ (mm Hg)

2.0 ml
↓ Hb (7.5) ↔ VO₂(5) ↓ CvO₂ (5) ↓ PₐO₂ (27) ↓ TaO₂ (10) ↑ QT

ANEMIA

Tissue Hypoxia
COHb (50%) \xrightarrow{} \downarrow \text{CaO}_2 (10) \xrightarrow{} \uparrow \text{Affinity} \nabla \leftrightarrow \text{Vo}_2 (5) \nabla \downarrow \text{CvO}_2 (5) \nabla \downarrow \downarrow \text{PvO}_2 (15) \nabla \uparrow \text{FiO}_2 \nabla \uparrow \text{Elimination CO}
An approach to inadequate blood transport of O₂

\[ \dot{V}_{O₂} = \dot{Q}_T \cdot C (a - v) \text{ O}_2 \]

\[ \downarrow \dot{Q}_T \]
\[ \downarrow \text{PaO}_2 \text{ & } \text{SaO}_2 \rightarrow \downarrow \text{PvO}_2 \rightarrow \text{Anaerobic metabolism} \]

\[ \downarrow \text{Hb} \]

\[ \text{Rx} \rightarrow \uparrow \text{CaO}_2 \text{ (} \uparrow \text{Hb or } \uparrow \text{SaO}_2 \text{)} \]

\[ \uparrow \dot{Q}_T \]
↑ Dissolved O₂

**PaO₂** 650 mmHg  
↑ **CaO₂** 1.7 ml/100ml of bl.

<table>
<thead>
<tr>
<th><strong>CvO₂</strong></th>
<th>10 -------- 11</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SvO₂</strong></td>
<td>50 ----------- 58</td>
</tr>
<tr>
<td><strong>PvO₂</strong></td>
<td>27 ----------- 34</td>
</tr>
</tbody>
</table>

Anaerobic  
Aerobic
- ↓ Vo$_2$
- ↓ WOB
- Muscle relaxant
- PPV
- Cooling
Hyperventilation

- Shift ODC to the left
- Same PaO$_2$ $\rightarrow$ $\uparrow$O$_2$Sat $\rightarrow$ $\uparrow$CaO$_2$

- $\uparrow$CaO$_2$ $>$ $\uparrow$CvO$_2$
Mechanics of The Respiratory System
ความต้านทานต่อการหายใจ

- Elastic resistance
  - 1/C หรือ P/V
- Airway resistance
  - ΔP/F
- Tissue resistance
\[ \Delta P = \Delta \text{VOLUME} \cdot E + \text{FLOW} \cdot R \]
Dynamic and Static Relationships between Respiratory Pressures and Volumes Mechanics

- **Force**
  - $\Delta P$ (Applied pressure)

- **Motion**
  - $\Delta V$ (volume change)
  - $\dot{V}$ (Flow rate)
  - $\ddot{V}$ (volume acceleration)
Equation of Motion

\[ \Delta P = P_{el} + P_{r} + P_{acc} \]

\[ \Delta P = \Delta V \cdot E_{rs} + V \cdot R_{rs} + V \cdot I_{rs} \]

\[ P_{el} = \text{Elastic pressure} \]
\[ E_{rs} = \text{Elastance} \]
\[ P_{acc} = \text{Accelerative pressure} \]
\[ I_{rs} = \text{Inertia} \]
\[ P_{r} = \text{Resistance pressure} \]
\[ R_{rs} = \text{Resistance} \]
\[ \Delta P = \frac{\Delta P}{\Delta V} \]

\[ \Delta P = \Delta V \cdot E_r + \dot{V} \cdot R_{rs} \]

Flow = 0 ; \quad P_r = 0

\[ \Delta P = P_{el} \text{ (static)} \]

\[ \Delta P = \Delta V \cdot Er_s \]

\[ Er_s = \frac{\Delta P}{\Delta V} \]
• On ventilator
  \[ P_{\text{peak}} = P_{vl} + P_r \]

• Inflation hold
  
  - Flow (V) = 0
  - \( \Delta P = P_{el} \)
  - \( Ers = \Delta P / \Delta V \)
    
    \[ = \frac{10}{0.5} \]
    
    \[ = 20 \]
  
  - \( P_r = \Delta P - P_{el} \)
    
    \[ = 20 - 10 \]
    
    \[ = 10 \]
  
  - \( Rrs = P_r / \text{flow} \)
    
    \[ = 10 \]
NORMAL

\[ V_T = 1.01 \quad \dot{V} = 2.0 \text{ lps} \]

\[ \text{Pel} = 20 \quad E = 20 \]

\[ \text{Pr} = 20 \quad R = 10 \]
• Pulmonary edema
• ARDS
• Pneumonia
Static P-V curve

Normal Respiratory System

Pulmonary Edema

% TLC

\[ \frac{\Delta V}{\Delta P} \]

PEEP

Compliance = \[ \frac{\Delta V}{\Delta P} \]

cm H₂O

Pao

20  40  60
ABNORMAL RESISTANCE

\[ V_T = 0.51 \quad V = 1.0 \text{ lps} \]

\[ P_{el} = 10 \quad E = 20 \]
\[ P_T = 50 \quad R = 50 \]
Measurement Of Intrinsic PEEP
Scope

- Structure and Function
- Ventilation
- Perfusion
- Ventilation perfusion relationship
- Mechanics of breathing
- Transportation
  - Diffusion
  - Control of breathing