The respiratory system

Sigurd Steinshamn, Lung Department,
St. Olavs University Hospital, Trondheim
Functions of the respiratory system:

• **Gas exchange** (O2 uptake and CO2 elimination. Dependent on adequate respiratory and cardiovascular functions)

• **Regulation of blood pH** (dependent on blood CO2 levels)

• **Voice production** (vocal cords)

• **Olfaction** (nasal cavity)

• **Innate immunity**
Anatomy of the respiratory system:

- **Upper respiratory tract**
  - external nose
  - nasal cavity
  - pharynx (throat) and associated structures

- **Lower respiratory tract**
  - larynx
  - trachea
  - bronchi
  - lungs
Figure 15.1  The Respiratory System

The upper respiratory tract consists of the external nose, nasal cavity, and pharynx (throat). The lower respiratory tract consists of the larynx, trachea, bronchi, and lungs.
Upper lobe
Middle lobe
Lower lobe
Upper lobe with lingula
The respiratory membrane is where gas exchange between air (alveoli) and blood takes place.
8.8 Alveolus and the Respiratory Membrane

The alveolus is a tiny sac that is lined with a layer of simple squamous epithelium. The alveolus is surrounded by a rich network of capillaries, which facilitates the exchange of gases between the air in the alveolus and the blood in the capillaries. The respiratory membrane, which is the interface between the alveolar fluid (with surfactant) and the capillary endothelium, is very thin and allows for efficient diffusion of gases. This process is crucial for the exchange of oxygen and carbon dioxide, ensuring that the body receives oxygen and eliminates carbon dioxide.
BR – bronchus
BL – bronchiole
TBL – terminal bronchiole
RBL – respiratory bronchiole
AD – alveolar duct
AS – alveolar sac
Ventilation and lung volumes
Ventilation – process of moving air into and out of the lungs (”bellow function”)

- **Inspiration** – movement of air into the lungs (inspiratory muscles)
- **Expiration** – movement of air out of the lungs (expiratory muscles/passive process)

The *primary function* of the ventilation is uptake of O₂ and elimination of CO₂ to maintain a constant body niveau of O₂ and CO₂
Chest cage
Movement of diaphragm
At eqilibrium (after normal expiration):

*Elastic properties* (recoil pressure) pulls lungs *inwards* and thoracic cage *outwards*.
Intrapleural pressure is *negative* (i.e. lower than atmospheric pressure)
Normal

\( P = 0 \)

\( P = 0 \)

\( P = -5 \)
Pneumothorax
Pressure changes and air flow:

• Changes in volume results in changes in pressure
• Air flows from areas of higher to lower pressure
Before inspiration
During inspiration
Expiration

Positive pressure

18 8 0
**TIDAL VOLUME**
500 ml

**ANATOMICAL DEAD SPACE**
150 ml

**TOTAL VENTILATION**
6000 ml/min

**FREQUENCY**
12/min

**ALVEOLAR VENTILATION**
4200 ml/min
(=350ml x 12)

**BLOOD VOLUME PULMONARY CIRCULATION**
5000 ml/min
Lung volumes and capacities:

Spirometry: method of measuring volumes of air that moves into and out of the lungs ("dynamic lung volumes")

Pulmonary capacity: the sum of two or more pulmonary volumes
### Lung Volume/Capacity

<table>
<thead>
<tr>
<th>Lung Volume/Capacity</th>
<th>Definition</th>
<th>Average Values (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TV (Tidal Volume)</strong></td>
<td>Volume inspired or expired per breath</td>
<td>Men: 600</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Women: 500</td>
</tr>
<tr>
<td><strong>IRV (Inspiratory Reserve Volume)</strong></td>
<td>Maximum inspiration at end of tidal inspiration</td>
<td>Men: 3000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Women: 1900</td>
</tr>
<tr>
<td><strong>ERV (Expiratory Reserve Volume)</strong></td>
<td>Maximum expiration at end of tidal expiration</td>
<td>Men: 1200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Women: 800</td>
</tr>
<tr>
<td><strong>TLC (Total Lung Capacity)</strong></td>
<td>Volume in lungs after maximum inspiration</td>
<td>Men: 6000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Women: 4200</td>
</tr>
<tr>
<td><strong>RLV (Residual Lung Volume)</strong></td>
<td>Volume in lungs after maximum expiration</td>
<td>Men: 1200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Women: 1000</td>
</tr>
<tr>
<td><strong>FVC (Forced Vital Capacity)</strong></td>
<td>Maximum volume expired after maximum inspiration</td>
<td>Men: 4800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Women: 3200</td>
</tr>
<tr>
<td><strong>IC (Inspiratory Capacity)</strong></td>
<td>Maximum volume inspired following tidal expiration</td>
<td>Men: 3600</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Women: 2400</td>
</tr>
<tr>
<td><strong>FRC (Functional Residual Capacity)</strong></td>
<td>Volume in lungs after tidal expiration</td>
<td>Men: 2400</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Women: 1800</td>
</tr>
</tbody>
</table>
Alveoli

Emphysema

Normal alveoli
COPD and smoking

Lung function

Normal course

Vulnerable smoker

After smoke cessation

Years
Gas exchange
Gas exchange

• transport of O₂ og CO₂ between the gas in the lungs and the cells of the organism
Diffusion of gases in the lungs:
- O₂ moves from the alveoli into the pulmonary capillaries (pressure gradient)
- CO₂ moves from the pulmonary capillaries into the alveoli (pressure gradient)

Diffusion of gases in the tissues:
- O₂ diffuses from the capillaries into interstitial fluid and from interstitial fluid into the cells (pressure gradient)
- CO₂ diffuses from the cells into interstitial fluid and from interstitial fluid into the capillaries (pressure gradient)
The *diffusion capacity* determines a) the rate of exchange of oxygen (O₂) between the lungs and the blood and b) the rate of exchange of carbon dioxide (CO₂) between the blood and the lungs for exhalation.
Diffusion capacity for oxygen (from lungs to blood) is determined by:

1. **Gas exchange area (surface area)** between the alveoli and capillaries
2. **Thickness** of the alveolocapillary membrane
3. **Pressure difference** (alveoli – blood)
4. **Available amount of** hemoglobin
The blood passes through the lung capillaries during 1 second at rest. Diffusion of O₂ takes place during 0.25 – 0.3 sec

Therefore: Sufficient reserve capacity in health!
Diffusion of respirable gases:

CO$_2$ diffuses 20 times more easily through the alveolar wall than O$_2$.

Reduced diffusion capacity causes failure of oxygenation and represents normally no problem with respect to elimination of CO$_2$. 
Oxygen and carbon dioxide transport
O₂ transport from atmosphere to mitochondria:

1. Ventilation

2. O₂ transport from the alveoli to binding to Hb in erythrocytes

3. Circulation

4. O₂ transport fra erythrocytes to mitochondria in tissue cells
Oxygen is carried in the blood in two ways:

1. In physical solution dissolved in the fluid portion of the blood (1.5% of the total oxygen in health), or
2. In loose combination with hemoglobin (Hb), the iron-protein compound in the red blood cell (98.5% of the total oxygen in health)
The oxygenation of hemoglobin to oxyhemoglobin depends entirely on the partial pressure of oxygen in solution

• At high oxygen pressure (in the lung capillaries), oxygen more easily binds to hemoglobin

• At low oxygen pressure (in the tissues), hemoglobin more easily releases oxygen to the tissues
More oxygen is released from hemoglobin if:

• O2 pressure is low
• CO2 pressure is high
• The pH is low
• Temperature is high

Beneficial in exercise (just think of the working muscle)
Carbon dioxide transport:

• Dissolved in plasma (7%)
• In combination with proteins, mainly hemoglobin (23%)
• In the form of bicarbonate ions (70%)
Control and regulation of ventilation:
Regulation of ventilation:

• CO₂ and pH more important than O₂
• Low pH and high CO₂ increase ventilation - as does low O₂
• Important for maintaining a stable niveau of pH and CO₂
• Nervous control

• Chemical control
Chemical control:

- **Central chemoreceptors**
  - Responds to pH (acidity) in the CSF – determined by CO$_2$

- **Peripheral chemoreceptors**
  - At the aortic arch
  - At the carotid bifurcation
  - Responds primarily to hypoxemia
central control

pons, medulla, other parts of the brain

sensors

effectors
Figure 15.16  Major Regulatory Mechanisms of Ventilation

The major regulatory mechanisms that affect the rate and depth of ventilation are shown. A plus sign indicates an increase in ventilation, and a minus sign indicates a decrease in ventilation.
VENTILATION IN EXERCISE
• *Abrupt increase* in ventilation (as much as 50% of total increase during exercise)
  – Learned component?
  – Activation of motor pathways (brain - cortical influence)
  – Body movements stimulates proprioceptors in joints of the limbs (peripheral influence)

• *Gradual increase* in ventilation (among other factors, temperature)

”Surprisingly” stable niveau of CO₂, O₂ and pH during heavy exercise

*Anaerobic threshold* (determines the maximum level for steady-state exercise)
Limitation of exercise capacity usually due to cardiovascular limitations and not ventilatory limitations (larger ventilatory reserve capacity)

However: the adaptability of the structural and functional components of the pulmonary system to chronic exercise training are considerably less than adaptations observed for the cardiovascular and neuromuscular systems
Aging and the respiratory system

- Decreased vital capacity (stiffness of chest wall and weakening of respiratory muscles)
- Increased residual volume
- Decreased gas exchange across the respiratory membrane

May lead to decreased ability to perform exercise