The Respiratory System
Respiratory system functions mainly as gas exchange system for \( O_2 \) and \( CO_2 \)

\[ \rightarrow \text{cellular respiration} \] (energy production)
closely tied to circulatory system

**General Functions of Respiratory System:**
1. \( O_2 \) and \( CO_2 \) exchange between blood and air
2. speech and vocalization
3. sense of smell
4. helps control acid base balance of body
5. breathing movements help promote blood and lymph flow

Anatomy of the Respiratory System

**Main Organs:**
- nose
- pharynx
- larynx
- trachea
- primary bronchi
- lungs:
  - bronchioles
  - alveoli/respiratory membrane

these organs can also be subdivided into:

**Upper respiratory tract**
- nose \( \rightarrow \) pharynx \( \rightarrow \) larynx

**Lower respiratory tract**
- respiratory organs of the thorax
  - the lower respiratory tract fills most of the Thorax (Thoracic Cavity)
  - major portion is inside lungs

air passageways must be held open at all times

- nasal passageways and throat follow passages in skull bones and cartilage
- others held open by rings of cartilage

1. **Nose**
   separated from mouth by hard and soft palate
   - cleft palate – bones don’t unite completely produces difficulties in swallowing
   each nasal cavity is divided into 3 passageways by **turbinates**
   - creates narrow, turbulent passageways to insure that all air makes contact with mucous membranes
   lined with ciliated mucous membranes containing **goblet cells**
   - membranes are heavily vasculairized
   - remove bacteria, debris and particles
   - mucous blanket: produces 125 ml/day cilia move it 1-2 cm/min
   - warms and moisturizes air entering lungs
   - also contains receptors for smell
   - nasolacrimal ducts drain into nasal cavity
   paranasal **sinuses** are accessory structures:
   - sound resonance (other animals)
   - warm and moisten air lighten skull

2. **Pharynx (throat)**
   from base of skull to junction with esophagus and trachea
   - 5” long
   made of muscle and lined with mucous membrane
   junction between digestive and respiratory systems
   divided into three regions:
   a. **Nasopharynx**
      - behind nose to level of soft palate
      - includes uvula
      - tonsils (adenoids)
      - auditory tube (eustachian tube) drains here
   b. **Oropharynx**
      - behind mouth
      - from soft palate to level of hyoid bone
      - palatine and lingual tonsils
   c. **Laryngopharynx**
      - from hyoid bone to esophagus/larynx

3. **Larynx (voice box)**
   - enlarged beginning portion of trachea
   - composed of cartilage and muscles
opening into larynx = **glottis**

prevent food from entering lower respiratory system

sound → speech, singing, etc

9 cartilages (3 large, 6 small):

- **epiglottis** – covers glottis when swallowing
  - in infants, the epiglottis is high in throat and touches the soft palate → allows infants to eat and breath at same time, epiglottis deflects foods away from glottis
  - this advantage is lost by age 2 when root of tongue becomes more muscular forcing larynx lower

- **thyroid cartilage**
  - largest cartilage of larynx
  - testosterone stimulates the growth of the laryngeal prominence so it becomes larger in males than in females = **adam's apple**

- **cricoid cartilage**
  - smaller cartilage below thyroid
  - connects larynx to trachea

2 muscular folds within larynx:

- upper: **(false) vocal cords** (=vestibular folds)
  - close glottis during swallowing

- lower: **(true) vocal cords**
  - wall of larynx are very muscular
  - some of these muscles help to control these two pairs of folds

4. **Trachea**

extends from larynx to bronchi

surrounded by "C" – shaped bands of cartilage ends joined by bands of muscle tissue

→ holds walls open, prevents collapse

lined by pseudostratified ciliated columnar epithelium

tracheotomy

5. **Bronchi**

trachea divides into two branches = **bronchi** which enter each lung

bronchi resemble trachea in structure

→ also supported by C-shaped cartilages

also have lots of elastic connective tissue

6. **Lungs**

the remainder of the respiratory system is contained within the two lungs

- left lung → 2 lobes
- right lung → 3 lobes

all organs between the two lungs are located in the **mediastinum**

mediastinum includes:

- heart
  - heart is in its own sac = pericardium
  - esophagus
  - trachea
  - major blood vessels attached to heart

lungs are located in **pleura cavity**

- **visceral pleura** covers outer surface of lungs
- the pleurae and pleural fluid:
  - 1. help reduce friction
    - act as a lubricant
    - **pleurisy**=pleurae are dry and inflamed
  - 2. create a pressure gradient
    - as rib cage expands to draw air into the lungs
  - 3. compartmentalization
    - surround each lung and isolate it from other and pericardial sac
    - prevent infections from spreading easily from one thoracic organ to another

7. **Bronchioles**

smallest branches of “respiratory tree”

<1mm diameter

no cartilage rings

but larger branches may have small patches of cartilage

lined with ciliated cuboidal epithelium and layer of smooth muscle

asthma affects the smallest terminal bronchioles

8. **Alveoli**

smallest bronchioles (respiratory bronchioles) have
clusters of tiny sacs branching off = alveoli
"grapelike clusters"

300-500 Million alveoli/lung

single cell layer thick (squamous epithelium)

enveloped by capillaries

alveoli are the "functional units" of the respiratory system

actual site of gas exchange with blood

alveoli increase in number and size until adolescence
after adolescence, can increase in size only and if damaged,
have only limited ability to repair themselves

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**Physiology of Respiration**

**Pulmonary Ventilation**

we move ~500 ml of air in and out of lungs with each breath

involves moving air down a pressure gradient

breathing involves 2 processes:

- **inspiration**
- **expiration**

1. **Inspiration**

   an active contraction of diaphragm

   → innervated by phrenic nerve

   may also involve contraction of the external intercostals

   contraction of diaphragm lowers pressure in thoracic cavity:
   outside pressure > pressure in lungs → lungs inflate

   the "work" required for normal breathing is
   ~1-2% of body’s total energy expenditure

   during heavy exercise that may increase to
   15% of energy expended

2. **Expiration**

   normal expiration is mainly a passive process

   → relaxation of diaphragm

   volume of chest decreases, forcing air out of lungs

   may also involve contraction of internal intercostals & muscles of abdominal wall

   pressure in thoracic cavity is kept lower than pressure in outside air

   → keeps lungs inflated

   **pneumothorax**

   opening in chest cavity

   eliminates pressure differential

   causes lungs to collapse

**Surface Tension** also plays an important role in
keeping the lungs inflated

outer surface of lungs and inner surface of alveoli
are covered with thin film of water

water has a high surface tension (very “sticky”)

on outer surface of lungs:

→ visceral pleura tends to stick to parietal pleura

creates slight negative pressure

helps to inflate lungs during inspiration

on inside of alveoli:

→ tends to cause the alveoli to collapse upon themselves

counteracted by:

a. lungs never completely deflated;
   always contain some air

b. secrete **surfactant**

   reduces surface tension in alveoli

   not produced until 8th month of pregnancy

   → respiratory distress syndrome

**Respiratory Volumes**

the volume of air exchanged in breathing is measured
with a **spirometer**

provides information on pulmonary functions

eg. **Tidal Volume (TV)**

normal volume of air with each breath

small part of total lung capacity (~10%)

~500 ml
eg. Vital Capacity (VC)

- largest volume of air that can be moved into or out of lungs
- vital capacity is affected by:
  a. overall size of individual, gender
  b. volume of blood in lungs
  c. excess fluid in pleural or abdominal cavity
  d. loss of lung elasticity
  e. misc health related factors (eg. smoking, exercise, etc)

eg. Residual Volume

- air that cannot be removed from lungs
- ~1200 ml
- removed in pneumothorax

Nonrespiratory Air Movements

- speech ➔ communication
- cough ➔ removes junk from lower resp passages, reflex
- sneeze ➔ clears upper resp passages, reflex
- laughing, crying ➔ emotional state
- hiccup ➔ spasmodic contraction of diaphragm
- yawn, sigh ➔ with shallow breathing, eventually surface tension

  can overcome surfactant and alveoli start to collapse; an occasional deep breath reinflates them ➔ forces lungs open again since chest muscles are stronger than surface tension

Alveolar Gas Exchange

- the exchange of gasses in the lungs takes place between alveolar air and venous blood
- gas exchange occurs across the lining of the alveoli and capillaries (2 cell layers thick)

  ➔ respiratory membrane
  - total surface area ~ 70 (60-80)m²
  - (=760 ft² ~20'x38'; = tennis court)

Gas exchange is the result of simple diffusion down oxygen and carbon dioxide concentration gradients:

<table>
<thead>
<tr>
<th>Alveoli</th>
<th>Blood Entering Lungs</th>
</tr>
</thead>
<tbody>
<tr>
<td>PO₂</td>
<td>105mmHg</td>
</tr>
<tr>
<td>PCO₂</td>
<td>39mmHg</td>
</tr>
<tr>
<td></td>
<td>40mmHg</td>
</tr>
<tr>
<td></td>
<td>46mmHg</td>
</tr>
</tbody>
</table>

The exchange of gasses in tissues is also by simple diffusion:

<table>
<thead>
<tr>
<th>Blood leaving lungs</th>
<th>Tissues</th>
</tr>
</thead>
<tbody>
<tr>
<td>PO₂</td>
<td>104mmHg</td>
</tr>
<tr>
<td>PCO₂</td>
<td>40mmHg</td>
</tr>
<tr>
<td></td>
<td>≤40mmHg</td>
</tr>
<tr>
<td></td>
<td>≥45mmHg</td>
</tr>
</tbody>
</table>

Transport of Gasses in Blood

A. Oxygen

- almost all hemoglobin in blood going through lungs manages to pick up oxygen

  ➔ 98% saturation
  - versus ~70% saturation in venous blood

  ➔ hemoglobin has a very high affinity for O₂

- only ~2% of O₂ is carried dissolved in plasma

  Hyperventilation doesn’t increase PO₂ of blood

  only slightly increases dissolved O₂ concentrations

  ➔ may deliver a little more O₂ to tissues but not much

- the amount of oxygen carried in the blood then is mainly dependent on the amount of hemoglobin in blood

  4 O₂/hemoglobin ➔ 250 Million Hb/RBC ➔ 1 Billion O₂/RBC

- anemia decreases oxygen transport

- CO binds to Hemoglobin even more strongly than does oxygen

  ➔ CO poisoning (takes very little, but continuous exposure)

2. Carbon Dioxide

transported in blood three major ways:

1. 10% dissolved in plasma ➔ >20x’s more soluble than O₂

2. 20% bound to hemoglobin

  • CO₂ binds to amino group of hemoglobin
  • (O₂ binds to heme portion) ➔ carbaminohemoglobin

3. 70% converted to bicarbonate ions

  ![carbonic anhydrase](https://example.com/carbonic-anhydrase)

  - this reaction occurs mainly inside RBC’s
  - bicarbonate ions are then released into the plasma

  oxygen release is enhanced by CO₂ loading

Regulation of Respiration

- the heartbeat and breathing are the two most conspicuous rhythmic processes occurring in the body

  - the heart has its own pacemaker
  - the lungs do not ➔ breathing depends on rhythmic
stimuli from the brainstem
breathing involves coordination of several groups of voluntary muscles
the lungs themselves are not actively involved in the process
normal breathing is automatic, rhythmic
controlled by respiratory reflex centers in brainstem

A. Respiratory Reflex Centers
Three reflex centers in brain that regulate breathing:
1. respiratory center: medulla
   establishes basic rhythm of breathing
   maintains automatic breathing rate
   \( \rightarrow 12-15 \text{ breaths/min} \)
2. apneustic: pons
3. pneumotaxic center: pons
   the two centers in pons insure a smooth transition between inspiration and expiration
   helps maintains rhythmicity of breathing

when connection between medulla and pons are cut breathing becomes abnormal
\( \rightarrow \) gasps

The Aging Respiratory System
pulmonary ventilation declines steadily after 20’s
\( \rightarrow \) costal cartilages and joints become less flexible
\( \rightarrow \) lungs have less elastic tissue
\( \rightarrow \) fewer alveoli
decline in volume of inhaled air (TV) and Vital Capacity
also less capable of clearing lungs of irritants and pathogens and therefore more susceptible to respiratory infections
\( \rightarrow \) pneumonia causes more deaths in old age than any other infectious disease

diseases of the respiratory system

Restrictive Disorders
\( \rightarrow \) stiffen lungs, reduce compliance and vital capacity
eg. pulmonary fibrosis
respiratory tissue is replaced by fibrous scar tissue
effect of TB and black lung disease

Obstructive Disorders
\( \rightarrow \) narrow the airway and interfere with airflow
expiration requires more effort
eg. airway obstructions, bronchoconstriction, tumors or aneurysms that push on airways
chronic obstructive pulmonary diseases:
asthma
chronic bronchitis
emphysema

A. Diseases of inadequate ventilation

1. Pneumothorax
collapsed lung or lungs

2. paralysis of diaphragm muscle
due to injury to respiratory center of brainstem
eg. caused by polio which damages respiratory center
damage to nerves supplying diaphragm (phrenic nerve)

3. bronchial asthma
allergic reaction
excessive mucous secretions and constrictions of bronchioles

4. emphysema
progressive degenerative disease causing destruction of alveolar walls
may be due to chronic irritation (eg smoking)
loss of tissue elasticity

5. lung cancer
uncontrolled growth of cells crowd out normal cells

B. Diseases of Poor Gas Exchange

1. emphysema

2. infections
viral or bacterial
eg. hay fever, bronchitis
cause lining of tubes to swell and become inflammed

2. pneumonia
more severe result of respiratory infection
bacterial or viral
alveoli fill with fluids

3. tuberculosis
tubercles formed to wall off bacterial infection
if infection is not controlled may invade more lung tissue causing fibrosis
causes extensive destruction of lung tissue

4. Respiratory Distress Syndrome
collapse of lungs in baby due to lack of surfactants