

Chapt. 42 – Circulation and Gas Exchange

1 mm rule: **Diffusion** is an effective means of transporting substances (*e.g.*, gases) only when the distance is < 1 mm

Open circulatory systems greatly increase the efficiency of transport of substances within a body relative to diffusion [Fig. 42.3]

Closed circulatory systems are even more efficient than **open circulatory systems** [Fig. 42.3]

In vertebrates: **circulatory system + gas exchange organs = cardiovascular system**

Fish have **2-chambered hearts** [Fig. 42.4]

A **single circuit** with 2 sets of **capillaries**, which limits maximum aerobic metabolic rates of fishes

Gill capillaries are the sites of gas exchange with the environment [Fig. 42.21]

Counter-current exchange helps maximize the efficiency of gas exchange [Fig. 42.21]

Amphibians have **3-chambered hearts** [Fig. 42.4]

Three chambers allows for **double circulation**, *i.e.*, **two circuits**, such that blood passes through a single set of capillaries in each round-trip from and back to the heart

In most amphibian larvae, the capillaries of the **pulmocutaneous circuit** are found in **gills**

However, most adult amphibians exchange gases through **lungs** and their **skin**

Mammals have **4-chambered hearts** [Fig. 42.4, 42.5, 42.6]

Right ventricle → **Pulmonary arteries** → **Capillaries of lungs** → **Pulmonary veins** → **Left atrium** → **Left ventricle** → **Aorta** → **Capillaries of the body** → **Anterior and posterior vena cava** → **Right atrium** → **Right ventricle** (go back to beginning...)

Heart valves prevent backflow of blood

Atrioventricular valves

Semilunar valves

The Cardiac Cycle [Fig. 42.8]

The **pacemaker (sinoatrial node)** sets the tempo of the heartbeat

The signals spread through the **atria**, but are delayed at the **atrioventricular node**

The signals are then conveyed via **Purkinje fibers** to the **apex** of the heart

A wave of contraction across the **ventricles** ensues

The Cardiac Cycle [Fig. 42.7]

During **atrial and ventricular diastole**, the whole heart is relaxed

Atrial systole follows, in which the atria contract

Ventricular systole follows, in which the ventricles contract

Heart rate (pulse)

Nervous system and hormones control the **pacemaker's** rhythm

Resting pulse is around 70 beats per minute

Strenuous activity or stress can raise the pulse to 170 or more

Measuring blood pressure [Fig. 42.12]

Blood pressure is measured by two values:

Systolic pressure – during ventricular contractions

Diastolic pressure – between ventricular contractions

The cuff is inflated to stop blood flow in the arm

Pressure is released from the cuff until blood flow is just audible below the cuff; blood passes through the cuff only at highest pressure (**systolic pressure**)

Further pressure is released from the cuff until blood flow is continuous and no longer audible (**diastolic pressure**)

Arteries, veins, capillaries [Fig. 42.9]

Blood flows out of and away from the ventricular chambers via **arteries**

Arteries have thick walls whose elasticity helps keep blood moving

Arteries branch into **arterioles**

Arterioles branch into **capillaries**

Gas exchange occurs across **capillaries**, whose walls are one cell thick

We have 50,000 miles of them

Few human cells are > 100 μm from a capillary

Capillaries connect to **venules**

Venules connect to **veins**

Veins have **valves** that help prevent backflow

What is blood?

Blood is the fluid that carries nutrients, gases, hormones and wastes around the body

Blood consists of:

plasma (the liquid part) 55% of volume

cellular components 45% of volume

(**red blood cells, white blood cells, platelets**)

Average adult human has 5 to 6 L of blood (about 8% of body mass)

Plasma is a straw-colored liquid that contains dissolved proteins, salts, minerals, and hormones

Red blood cells = erythrocytes

These are the most numerous cells in the blood

Their dimpled shape gives them extra surface area

They are packed full of the pigment **hemoglobin**

Hemoglobin

Four subunit **polypeptide chains**

Each subunit polypeptide chain has an **iron-rich heme group**

Each heme group can reversibly bind one O_2 molecule

Carries ~ 70 times more O₂ than dissolves in the plasma
Also carries CO₂, but with much less affinity than for O₂

Red blood cells = erythrocytes

Produced in the **bone marrow**

Live ~ 120 days.

Dead and damaged cells are removed from circulation by the **liver** and **spleen**

White blood cells → 5 types of leukocytes [Fig. 42.16]

Produced in the **bone marrow**

Collective function is to fight infection

Platelets

Fragments that bud off of larger cells in the **bone marrow**

They are especially valuable in the **clotting response**

A **clot** forms as platelets, RBCs, and a **fibrin** network stick together

The lymphatic system [Fig. 43.5]

Capillaries are leaky, and much fluid passes out of them into the interstitial spaces

The fluid is taken up by **lymph capillaries**, at which point the fluid is referred to as **lymph**

Lymph vessels are valved and empty into main veins of the circulatory system

Lymphocytes are also important components of lymph

Lymphocyte-rich nodes help filter the lymph and serve as sites of attack on microbial invaders

Structures labeled in the figure (Fig. 43.5) are especially active traps of microbial invaders

Lymphocytes develop in the **thymus** and **bone marrow**

Just like other organ systems, the lymphatic system can malfunction

Elephantiasis – caused by a parasitic worm, most common in parts of Africa, reduces the lymphatic system's ability to take up fluids that leak out of capillaries

The respiratory system [Fig. 42.23]

Nasal cavity → Pharynx → Larynx → Trachea → Bronchi → Bronchioles → Lungs

Each lung contains ~ 2 million alveoli, with a total surface area of ~ 75 m²

Alveoli have thin, moist walls and are surrounded by capillaries

Oxygen diffuses from the air in the air spaces of the alveoli into the blood of the capillaries

Carbon dioxide diffuses from the blood of the capillaries into the air of the air spaces of the alveoli

Diaphragm [Fig. 42.23 & 42.24]

When the diaphragm contracts, the chest cavity expands, and the lungs fill with air

Birds have especially efficient respiratory systems [Fig. 42.25]

When a bird inhales, some of the air passes through its lungs and some fills its air sacs

When a bird exhales, air continues to move in the same direction through the lungs, as the air sacs empty

The microscopic, tube-like chambers of gas exchange in bird lungs are known as **parabronchi**

Cardiovascular diseases

Disorders of the heart and blood vessels

Leading causes of death in the USA (~ 1 million people each year)

Hypertension (high blood pressure), often caused by constriction of the arteries and arterioles, can strain the heart

Hypertension often results from **plaque** buildup

Plaques are thickened artery and arteriole walls, in which the smooth muscle has become infiltrated by lipids (especially low-density lipoproteins, LDL's, the "bad cholesterol")

Atherosclerosis is the condition in which plaques impair circulation

Arteriosclerosis is a more advanced condition in which plaques become hardened by calcium deposits

Plaques are often sites of clotting within vessels; **thrombus** (clot formed & found at the site of blockage) or **embolus** (clot transported within the blood to its site of blockage)

Restricted blood flow within the **coronary arteries** (which deliver blood to heart tissues) may cause chest pains (**angina**)

Blockage from a thrombus or embolus of coronary arteries is one cause of **heart attack**

A similar blockage in the brain is a cause of **stroke**

Exercise, low-fat diet, and abstinence from smoking and alcohol abuse all promote a healthy heart

Smoking and health (a gratuitous public-service announcement)

Nicotine in tobacco smoke is a powerfully addictive drug

Each year 430,000 people in the USA die from smoking related diseases

Principal causes of death are lung cancer, emphysema, chronic bronchitis, heart disease, strokes, and other cancers

Smoking costs U.S. tax payers about \$100 billion annually in health care for the uninsured and losses of productivity

Toxins in tobacco smoke inhibit the cilia that line the respiratory tract so that they cannot remove particulates

Toxins also impair white blood cells' abilities to combat infectious microbes, which leads to chronic infections like bronchitis

Emphysema occurs as alveoli become brittle and rupture, creating holes in the lungs

Carcinogens (cancer-causing agents) in tobacco smoke accumulate in the lungs

Passive smoking = breathing second-hand smoke

Estimated to cause 3,000 deaths from lung disease and 37,000 deaths from heart disease in non-smokers in the U.S. each year

Healing begins as soon as someone quits smoking

Risks of lung cancer, heart attack, and other diseases gradually diminish after someone quits smoking, so it's never too late to quit!