Introduction

The cardiovascular system constitutes one of the major coordinating and integrating systems of the body. The main function of the CVS is to transport and distribute essential elements (oxygen, glucose) to the tissues and to remove byproducts of metabolism (CO2, lactic acid, urea). Additionally, the CVS shares in the control of body temperature, transport of hormones.

The elements of the CVS that accomplish these tasks is the blood and its constituents. Blood flows is in closed circle, hence the name "circulatory system".

The anatomical features that help in this mode of transport are a series of distributing vessels, which eventually branch into smaller vessels to allow efficient exchange with the tissues. After exchange, blood is collected into collecting ducts that complete the circular pathway.

Blood is not static but constantly moving thanks to the presence of a pump, the heart. The heart is the center and crucial element of the CVS which we shall examine below.

The Heart

- Located in the mediastinum, (middle of the thoracic cavity), resting on diaphragm
- Size of a closed fist; ~ 300 g and apex slightly tilted to the left
- Pumps ~ 5-6 L/min

The Heart Wall Anatomy

The heart is covered by a serous membrane (pericardium)

- Parietal pericardium
- Visceral pericardium = epicardium
The parts of the heart wall are:
- Epicardium (connective tissue part of the pericardium that hugs the heart)
- Myocardium: actual cardiac muscle tissue
- Endocardium: thin layer of endothelial cells protecting inside of heart wall and continuous with blood vessels

**CardioVascular Blood Flow**

The main function of the heart is to circulate oxygen through the body and to release CO\textsubscript{2}. Uptake of O\textsubscript{2} and release of CO\textsubscript{2} are processes that occur in the lungs and the CVS has specific branches that route blood to the lungs.

3 major blood vessels return de-oxygenated blood (blood that has served the tissues) to the heart:
- Superior Vena Cava: returns blood from body parts superior to the heart
- Inferior Vena cava: returns blood from body parts inferior to the heart
- Coronary sinus: drains blood from the coronary vessels that supply the heart itself

Returned blood flows from these vessels into the right atrium, enters the right ventricle and leaves the heart via the pulmonary trunk.

The pulmonary trunk divides into right and left pulmonary arteries and serves the lungs for gas exchange in the alveolar capillary beds.

Oxygenated Blood returns to the heart via pulmonary veins that enter the left atrium and flows into the left ventricle.

Blood leaves the heart again to serve the body via the aorta. The aorta arches downwards to become the dorsal aorta. The aortic arch contains 3 arteries that supply the head:
- Brachiocephalic
- Left common carotid
- Left subclavian artery

The heart can thus be viewed as a dual pump, each pump serving a different purpose:
- the right half of the heart serves the pulmonary circuit
- the left half of the heart serves the systemic circuit
Valves of the Heart

To prevent back flow of the blood in the heart and to ensure efficient transfer of the blood, several valves occur at key points. They only open in response to pressure and only open in a one directional way.

**Atrioventricular valves (AV-valves)**
- Located between atrium and ventricle
- Right AV-valve = tricuspid valve (has 3 flaps)
- Left AV-valve - Bicuspid or mitral valve (2 flaps)
- Both are connected to the inner surface of the ventricle and held open by tendon like cords (chordae tendineae) and muscle extensions (papillary muscles)
- When the ventricles contract, blood pressure pushes the valve shut against the atria but the chordae prevent the valves to invert

**Semilunar Valves (SL-valves)**
- Located between the ventricle and the respective vein or aorta
- Pulmonary SL valve (right ventricle-pulmonary trunk)
- Aortic SL valve (left ventricle-aorta)
- Both have 3 semi lunar flaps

Rheumatic fever is a bacterial infection that causes damage to the bicuspid and aortic SL valve. Usually starts with a strep throat infection.

**Coronary Vessels**

Because the heart has such a thick layer of tissue, it needs blood supply as well to provide heart tissue with oxygen and nutrients and to remove waste products. This is accomplished by the coronary circulation.

- Two coronary arteries (left and right) branch from the ascending aorta
  - Left coronary artery divides into
    - anterior interventricular branch (supplies both ventricles)
    - circumflex branch (provides left atrium, left ventricle)
  - Right coronary artery which divides into
    - posterior interventricular branch
    - marginal branch (provides the right ventricle)
Microscopic Anatomy

- Cardiac cells are short, fat, branched and interconnected
- The interconnection is at the intercalated discs
  - This contrasts with skeletal muscle fibers which are independent structurally and functionally
  - At the intercalated discs, heart cells have many desmosomes and gap junctions
  - This makes that the cells are electrically coupled and the entire myocardium behaves as a single unit (syncytium)
- Cardiac cells are striated, have sarcomeres
  - 25% of the cell volume is mitochondria (2% in skeletal muscle)
  - Less T-tubules that don’t dip into the cell as deep and no triad system (less developed SR)
- The heart needs oxygen and can use different kind of nutrients such as lactic acid, fatty acids, glucose

Electrical Conduction of the Heart

The heart is able to beat spontaneously without an intervening nervous system.
- Due to the presence of cardiac cells that fire spontaneous impulses at repeated intervals
- These cells are said to be autorhythmic and they have 2 functions
  - Set the rhythm of the entire heart (pacemaker)
  - They form the conduction system throughout the heart; assures coordinated contraction of the heart muscle
- Cardiac excitation begins in the Sino Atrial node (SA node) located in the right atrium
- Each impulse spreads through the atria and cause them to contract
- Impulse travels down the atrium and reaches the Atrioventricular (AV) node, located at the interphase between atrium and ventricle
- From here, the impulse enters the Bundle of His, and into the right and left branches, which travel within the septum between the ventricles
- The impulse travels down to the apex and along the Purkinje fibers back upwards along each ventricle outer wall.

Reduction of blood flow to the heart is called ischemia, which usually causes hypoxia (reduced oxygen supply).
Minor myocardial ischemia is accompanied by chest pain (angina pectoris).
Severe myocardial ischemia results in death of heart tissue and myocardial infarction.
The wave of depolarization brought about by the traveling of the impulse from SA node towards Purkinje fibers ensures that the heart contracts in a regular pattern: atria contract first followed by contraction of the ventricles.

The pace of the heart is set by the pacemaker at the SA node. It generates an initial impulse ~ 75 times per min. Since all cells in the conduction system are autorhythmic, they also generate impulses. However, the SA node is the fastest and thus sets the pace, stimulates the other regions to fire before they actually do.

Should the SA node become non-functional, then other regions of the heart will take over the firing rate but at their own rhythm. These are then called ectopic sites or an ectopic focus. The AV node for example generates 40-50 beats per min. Should the AV node become damaged, then the bundle of His takes over at a rate of 20 beats per min. This is too low for proper blood delivery through the body. That’s when an artificial pacemaker is needed.

Neurophysiology of the Heart

Action potentials of Autorhythmic cells.

The way autorhythmic cells generate their own impulses is because they do not maintain a stable Resting Membrane Potential. It occurs as follows:

- A gradual reduced K⁺ permeability occurs accompanied by some slow Na⁺ entry via “funny” sodium channels
- The reduced K⁺ outflow and Na⁺ inflow results in a slow depolarization
- When threshold is reached, fast voltage gated Ca²⁺ channels open (L-Calcium channels)
- Calcium rushes in, depolarizing the membrane, reversing the MP
- Calcium channels close, K⁺ channels open again and K⁺ rushes out causing the repolarization
- After repolarization, K channels gradually close again and the slow depolarization phase starts over again.
Action potentials in Cardiac Muscle

The initial process of depolarization and action potentials over the myocardium is similar as in muscle and normal nervous tissue, with some important differences.

- Impulse from conduction system cause voltage gated Na channels to open; this results in a fast depolarization
- At the top of depolarization, Na channels close and slow voltage-gated Calcium channels open. This allows calcium to rush in and maintain the depolarization. It results in a plateau phase.
- Calcium channels close and voltage gated K channels open. K rushes out and start the repolarization phase

The plateau phase is due to the Ca influx. It also causes Ca release from the SR in the heart muscle and triggers the contraction phase in a similar way as in skeletal muscle. The required calcium influx needed for release of calcium from the SR is termed calcium–induced calcium release.

The End of contraction is when the cell is repolarized. It also requires Calcium to be pumped out of the cytoplasm. This is done by powerful Ca-pumps in the SR membranes that drive calcium back into the SR. Additionally, Calcium/Sodium antiports (a secondary active transport system) moves calcium out of the cardiac cell.

The Calcium influx during the plateau phase keeps the cardiac muscle depolarized for a longer time, extending the refractory periods. This is about 250 msec compared to 2-10 msec in skeletal muscle.

The refractory period in the heart is thus longer than the contraction itself. The possibility for rapid contractions in a tetanus form is thus not possible in a heart. Tetanus contractions would otherwise compromise the function of the heart !!!!