

Heart

I. Heart Anatomy-

Quick note: veins carry blood to the heart, regardless of whether blood has O₂ or not. For example, oxygenated blood from the lungs enters the heart via the pulmonary veins. Arteries carry blood away from the heart, regardless of whether blood has O₂ or not. For example, deoxygenated blood from the heart goes to the lungs via the pulmonary arteries.

A. Size, Location, Orientation

1. ~ Size of a fist, <1lb
2. Enclosed in the mediastinum (within that, specifically the pericardial cavity).
3. Posterior to sternum
4. ~ 2/3 of the heart lies on the left side of the midline of sternum. The left ventricle makes up the apex which “points” inferiorly toward the left hip.

B. Coverings of the Heart

1. Surrounding the heart is the pericardium: serous membrane (you may want to review this).
 - a. A double-layered, fluid filled sac.
 - b. The epicardium, or visceral pericardium, makes up the inner layer, directly surrounding the heart. The connective tissue of the epicardium contacts and connects to the heart.
 - c. The parietal pericardium makes up the outer layer
 - d. In between is pericardial fluid, which protects the heart & reduces friction from heart beat movement. The pericardial fluid is secreted by the simple squamous cells of the serous membrane.
2. The connective tissue of the parietal pericardium attaches to surrounding connective tissue, which stabilizes the pericardium

C. Brief Anatomy & Orientation –

1. Made up of 4 chambers: 2 atria & 2 ventricles; Atria are somewhat superior/posterior to ventricles
 - a. The atria both receive blood from other parts of the body.
 - i. The right atrium receives blood from the body
 - ii. The left receives blood from the lungs.

- b. The ventricles receive blood from their respective atria, & pump it away to other parts of the body.
 - i. The right ventricle receives blood from the right atrium & pumps it to the lungs.
 - ii. The left ventricle receives blood from the left atrium & pumps it to the body.

2. Orientation

- a. The atria lie somewhat superior & posterior to their respective ventricles.
- b. The heart kind of “lies” on its right side – in an anterior view, the right ventricle makes up the mid-section, the tip of the left ventricle is visible, & only the auricles of the atria are visible.
- c. In a posterior view, both atria are visible. Left ventricle is large, while only a portion of the right ventricle is visible.

D. Blood flow & valves: valves are non-muscular, connective tissue "flaps" between the chambers that prevent blood from going in a backward direction; ensure that no oxygenated blood mixes with deoxygenated blood.

I. Pathway of blood through the heart: The right side of the heart receives deoxygenated blood from the body and sends it to the lungs. This is called the Pulmonary Circuit. Pulmonary arteries carry de-O₂ blood from the heart to the lungs, and pulmonary veins carry O₂ blood from the lungs to the heart.

The left side of the heart receives oxygenated blood from the lungs and sends it to the body. This is called the Systemic Circuit. The vena cava and coronary sinus carry de-O₂ blood to the heart, and the aorta carries O₂ blood from the heart to the body

In a little more detail, Blood flows from the body into the right atrium, via a huge vein, the vena cava. Goes from right atrium to right ventricle, from right ventricle into the pulmonary trunk to lungs, from lungs into left atrium, from left atrium to left ventricle, back to body through the huge vessel, the aorta. Take a minute to draw blood flow through the heart.

2. When blood enters or leaves a ventricle, it must pass through a valve; a device to prevent backflow of blood. For instance, since the LA & LV are adjacent chambers, contraction of the ventricle should send blood into the left atrium as well as the right atrium. However, a one-way valve separating the left atrium from the left ventricle prevents this from occurring, and assures that all blood will be pumped to the body. Also, when the ventricle relaxes, blood from the adjacent vessels could leak back in (they're full!).

3. There are valves separating the right atrium from the right ventricle; the right ventricle from the pulmonary trunk; the left atrium from the left ventricle, and the left ventricle from the aorta.

a. The valves separating the atria from the ventricles are called **atrioventricular valves (AV)**. When the ventricle is relaxed (between contractions), the AV valves are limp.

When the ventricle is relaxed and the valves are open, blood pours in from the atria. For instance, deoxygenated blood from the right atrium pours into the right ventricle when it is relaxed.

Contraction of the ventricles shoots the flaps of the valves upward and together; they close. By closing, the valves between the right atrium and ventricle ensure that none of that blood goes **BACK** into the right atrium.

When the ventricle contracts, those flaps shoot up. Theoretically, they could simply turn inside out, like an umbrella turning inside out in a strong gust. But they don't, because there are small tendons attached to them that limit how far they can stretch. The tendons, called **chordae tendinae**, are attached to the heart muscle. Specifically, they attach to a muscle that contracts when the ventricle contracts. This causes the chordae to stiffen and hold the valves in place, shut. By the way, the chordae tendinae are our heart strings, which as you can see, would actually be quite difficult to tug on.

The valve between the **right** atrium and ventricle is **tricuspid**; it has three flaps. The valve between the **left** atrium and ventricle is **bicuspid**; it has two flaps. The left, bicuspid AV valve is also called the mitral valve.

b. The valves separating the ventricles from the aorta/ pulmonary trunk are called **semilunar** valves. Unlike the AV valves, the

semilunar valves are closed when the ventricles are relaxed. When, for example, the right ventricle contracts, blood shoots up and causes the flaps to open, allowing blood to enter the pulmonary trunk. When the ventricle relaxes, some blood in the pulmonary trunk backflows back toward the ventricle, which pushes on the flaps and causes them to close.

The semilunar valves both consist of 3 symmetrical flaps.

4. Blood flow, including valves:

Deoxygenated blood enters the right atrium via the superior vena cava (blood from the body superior to the diaphragm), the inferior vena cava (from the body inferior to the diaphragm) and from the coronary sinus (blood from heart muscle). You can see that I simplified blood entry to the right atrium in my earlier explanations.

De-O₂ blood exits the right atrium through the tricuspid atrioventricular valve, where it enters the right ventricle.

It enters the right ventricle from the right atrium through the tricuspid atrioventricular valve. When the ventricle contracts, blood exits through the pulmonary semilunar valve, into the pulmonary trunk. The trunk then divides into the right and left pulmonary arteries. Where will blood go from there?

Oxygenated blood returns from the lungs and enters the left atrium via 2 pairs of pulmonary veins (from the lungs)

Blood exits the left atrium via the bicuspid atrioventricular (mitral) valve, where it enters the left ventricle.

Oxygenated blood enters from the left atrium through the bicuspid atrioventricular valve. When the ventricle contracts, blood exits through the the aortic semilunar valve, into the aorta. Where will blood go from there?

E. Layers of the Heart Wall

1. Epicardium- the visceral pericardium (inner layer of the pericardium)

2. Myocardium- the muscular layer. This makes up the bulk of the heart, its the layer that contracts.

Cardiac muscle cells are arranged in a spiral pattern

Cardiac muscle cells are connected by intercalated discs, which consist of desmosomes and gap junctions. The gap junctions allow ions to flow between cardiac cells, so that contractions occur in a coordinated fashion (we'll get to that in heart physiology)

3. Endocardium- a thin membrane that lines the interior of the myocardium. It is continuous with the endothelium of the vessels entering and leaving the heart.

F. Chambers and Great Vessels (that means large vessels)

1. Partitions and Grooves

- a. The interatrial septum separates the atria from each other
- b. The interventricular septum separates the ventricles
- c. The Atrioventricular Groove, or coronary sulcus- on the external surface, a groove between the atria and ventricles
- d. The Anterior and Posterior Intrventricular Sulcus- on the external surface, grooves between the ventricles

2. The Atria- the receiving chambers

a. External structure- the auricles are hollow "flaps" that distend when filled with blood; increase the holding capacity of the atria

b. Internal structure-

the posterior surfaces are smooth

the anterior surfaces are ridged by bundles of muscle, called **pectinate muscles**

the **fossa ovalis** is a depression on the interatrial septum. This area is open during fetal development, and blood can

flow between the atria. In adults, it has closed, leaving just this depression.

c. Function of the atria- They receive blood: right atrium receives deoxygenated blood from the body via the vena cava. The left atrium receives oxygenated blood from the lungs via the pulmonary veins. They are relatively small and thin-walled, when compared with the ventricles. They contribute very little to propulsive pumping, but they do contract a little to squeeze every last bit of blood into the ventricles.

3. The ventricles

a. External Structure- when you look at the anterior surface of the heart, you mostly see the right ventricle. When you look at the posterior surface of the heart, you mostly see the left ventricle

b. Internal Structure-

i. Trabeculae Carneae- "crossbars of flesh"- line the interior walls; they are irregular ridges of muscle

ii. Papillary muscles stick out from the wall, and attach to the chordae tendinae (why is that, again?)

iii. The left ventricle is ~ 3 times more muscular than the right ventricle; it has to pump blood a much greater distance!

c. Function of the ventricles- propel blood out of the heart. Related to this function, the walls of the ventricles are much more muscular/thicker than those of the atria.

G. Coronary Circulation- the vessels that serve the heart muscle, which has a huge energy/O₂ demand

1. The arteries that serve O₂ blood to the heart originate at the base of the aorta: Right and left coronary arteries. They encircle the heart in the AtrioVentricular Groove.

a. The left coronary artery runs toward the left side of the heart, and divides into the Anterior Interventricular Artery, and the Circumflex Artery.

The Anterior interventricular artery follows the anterior interventricular sulcus, and supplies blood to the interventricular septum and the anterior walls of both ventricles.

The Circumflex artery follows the coronary sulcus, and supplies blood to the left atrium and posterior walls of the left ventricle.

b. The right coronary artery runs toward the right side of the heart, and divides into the Marginal Artery and the Posterior Interventricular Artery

The Marginal artery supplies blood to part of the right side of the heart

The Posterior Interventricular artery runs along the posterior interventricular sulcus, and supplies blood to the posterior ventricles.

2. Venous Return- how de-O₂ blood gets back to the heart- Remember that arteries branch into tiny capillaries, which exchange O₂ and CO₂ with tissue. The capillaries will then remerge into veins, which bring blood back to the heart.

The Great Cardiac Vein runs alongside the Anterior Interventricular Artery

The Middle Cardiac Vein runs alongside the Posterior Interventricular Artery

The Small Cardiac Vein runs alongside the Marginal Artery

The three merge together into the Coronary Sinus, which empties directly into the right atrium.

II. Heart Physiology

A. Cardiac Cycle- Includes all events associated with the flow of blood during one complete heartbeat

1. All 4 chambers in diastole, blood fills atria and ventricles

2. Atrial systole; at the end of atrial systole, ventricles hold the maximum amount of blood for this heartbeat: End Diastolic volume (EDV)
3. Atria return to diastole
4. Ventricular systole; blood pressure closes AV valves and opens semilunar valves. For an instant before the semilunars open, all valves are closed: Isovolumetric Contraction Phase. Some blood remains in ventricles after systole. This volume is called End Systolic Volume (ESV)
5. Ventricular diastole; blood pressure in ventricles drop, semilunar valves close and AV valves open. For an instant, all valves are closed: Isovolumetric Relaxation Phase.
6. Important points:

blood flow and valve activity are controlled by blood pressure gradients, which are caused by contraction and relaxation.

atria contract simultaneously, as do ventricles

blood volume pumped out by the right side equals that pumped out by the left side, but pressure changes between systole and diastole are greater on the left side.

B. Heart Sounds- closing of valves. See text.

C. Cardiac Output- amount of blood pumped out by each ventricle in one minute.

1. Background:

C.O. = Stroke volume (SV) X Heart Rate (HR); units of CO = mL/minute

SV = amount of blood pumped out per beat, or $SV = EDV - ESV$

Cardiac Reserve- difference between resting CO and maximum possible. Varies per individual.

2. Factors that affect CO- Anything that affects SV or HR will affect CO.
 - a. Factors that affect SV- anything that affects EDV or ESV will affect SV.

i. Preload- why is that?

ii. Contractility- increase in contractile strength, independent of muscle stretch/EDV. Increased influx of Ca^{++} increases contractility (ex, sympathetic stimulation)

iii. Afterload- backflow of blood into aorta/pulmonary trunk- increases pressure required by ventricles to push blood out

b. Factors that affect HR-

i. ANS- you know this so well you probably dream about it. How do sympathetic and parasympathetic input affect HR?

The hypothalamus monitors blood pressure, CO_2 and O_2 in the blood. It communicates with cardiovascular centers of the medulla to coordinate the degree of influence of each of the ANS divisions. The atria also contain baroreceptors that trigger sympathetic response when overstretched.

ii. Hormones- E, NE, T_3 all increase heart rate.

III. Cardiac Muscle and Electrical Events

A. Microscopic Anatomy of cardiac muscle cells

1. short, fat, branched; usually one centrally located nucleus; many, large mitochondria; T-tubules less salient, no triads, no terminal cisternae.

2. adjacent cells interlocked at intercalated discs, connected by desmosomes and gap junctions. Because of the gap junctions, myocardium is considered a functional syncytium.

3. loose connective tissue (endomysium) fills spaces between cells

4. There are two cardiac muscle cell types: conducting (autorhythmic) and contractile.

B. Conducting cells: location and function

1. Conducting cells- depolarize spontaneously. Initiate impulses/contraction of the myocardium. Arranged in a pathway through

the heart. The SinoAtrial (SA) node contains cells that depolarize the fastest of all the conducting cells. They therefore set the basic rate of the heart, and are called pacemaker cells.

The SA node would depolarize spontaneously about 80-100 times per minute if left to its own devices. Parasympathetic influence keeps the heart rate lower than that (varies per individual).

2. The Conducting System: the pathway of conducting cells-

SA node send impulses to AtrioVentricular node, both in right atrium. AV node leads to AV bundles, which branch to bundle branches and then Purkinje fibers.

C. Contractile cells and cardiac muscle contraction

1. Important ion channels of cardiac muscle cells:

fast Na^{++} - 2 doors open and close quickly, like those of skeletal muscle and nerve.

slow K^{+-} - one door opens slowly, like those of skeletal muscle and nerve

slow Ca^{++} - one door opens slowly

2. **Depolarization**- Ions enter cells through gap junctions from conducting cells. At threshold, fast Na^{+} activation gates open, Na^{+} rushes in. Slow Ca^{++} channels start to open slowly, and Ca^{++} starts to enter.

Ca^{++} is also released from the SR in response to ion influx; Ca^{++} causes contraction

[Na^{+} and Ca^{++} ions flow through gap junctions to adjacent cells, bringing them to threshold.]

3. **Plateau**- Around +30mV, Na^{+} deactivation gates close and remain closed until the cell is close to resting potential again. Remember that the inactivation gate CANNOT be reopened, so the time it stays closed represents the absolute refractory period.

Ca^{++} channels remain open even after Na^{+} channels close, and Ca^{++} continues to trickle in. This keeps the cell at ~ 0 mV for an extended period of time. There are two important things going on here: a) Ca^{++} keeps

coming in from outside, and is not sucked up by SR, so the cell remains contracted; b) the Na^+ inactivation gates remain closed for an extended period of time, since the voltage is so high. This prevents the cell from responding to another impulse.

6. Repolarization- Slow Ca^{++} channels start to close, slow K^+ channels start to open, and the voltage starts to become more negative and return to resting potential. Ca^{++} is actively pumped back to the SR and out of the cell. By the time the Na^+ deactivation gate reopens, all Ca^{++} has been returned and the cell has completely relaxed. In other words, the absolute refractory period is long enough to prevent tetanic contractions.

D. Electrical Events- the conducting system and ECG

1. SA node reaches threshold, sends impulse throughout atria, atria contract (P wave on ECG)

2. Impulse reaches AV node. Here there is a delay...the AV node takes longer to reach threshold (fewer ion channels). This delay allows the atria to relax before the ventricles contract.

Impulses do not travel from the myocardium of the atria to the myocardium of the ventricles; the cells are not connected by gap junctions and are separated by the fibrous skeleton (connective tissue). The only connection between the cardiac cells of the atria and the ventricles is between the AV node and the AV bundle.

3. Impulse travels to ventricles via the AV bundle, which then branches into bundle branches, which then branch into Purkinje fibers.

The cells of the bundles and bundle branches do not send ions to contractile cells; impulses reach contractile cells of the ventricles via the Purkinje fibers.

The ventricles contract (QRS complex); atria repolarize around here, but on an ECG that is masked by ventricular contraction.

4. The ventricles repolarize (T wave)