<u>Lecture 13 - The Heart Part 1</u>

The heart is a pump

- Transport system consisting of two side by side pumps
- Right side: receives oxygen-poor blood from tissues
    - Pumps blood to the lungs to get rid of CO_2, pick up O_2, via pulmonary circuit
- Left side: receives oxygenated blood from the lungs
    - Pumps blood to body tissues via systemic circuit

Size, location and orientation of heart

- Size of a fist
- Weighs less than 1 pound (0.45 kg)
- Location:
    - In mediastinum, between second rib and fifth intercostal space
    - On superior surface of diaphragm
    - Two-thirds of heart to left of midsternal line
    - Anterior to the vertebral column, posterior to sternum

Mediastinum: a membranous partition between two body cavities or two parts of an organ, especially that between the lungs

Diaphragm: dome-shaped, muscular and membranous structure that separates the thoracic (chest) and abdominal cavities in mammals.

vertebral column: also known as the backbone or spine, is part of the axial skeleton (wikipedia)

1. The outer layer of the heart is the pericardium

• double-walled, fibro-serous sac

a) fibrous pericardium

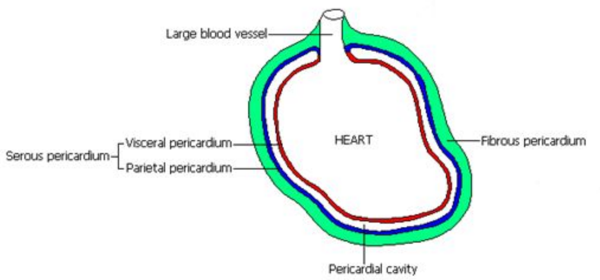
• protects heart

• anchors heart

• prevents overfilling of heart

b) serous pericardium: parietal & visceral (epicardium) layers

The pericardial cavity is important for preventing friction. It is filled with a thin film of fluid.



2. Myocardium is the bulk of the heart – cardiac muscle

• branching cardiac muscle cells arranged into bundles and the connective tissue wrappings of these bundles. This is known as the cardiac skeleton!

Three functions of the myocardial bundles/cardiac skeleton:

» reinforce myocardium internally & anchor cardiac muscle fibers

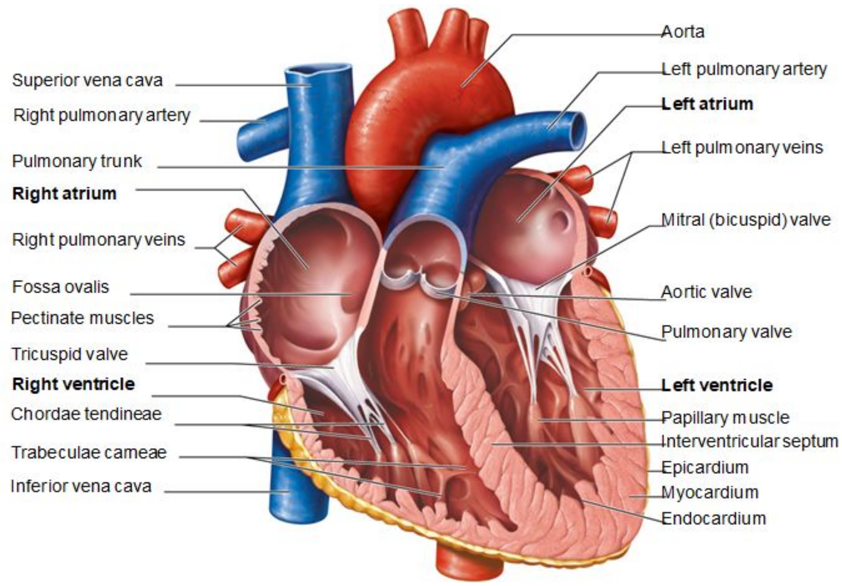
» provide additional support for great vessels & valves

» direct spread of action potentials across heart to specific pathways

3. Endocardium is inner layer of the heart wall

•Layer of endothelium + connective tissue layer on inner myocardial surface

•Continuous with endothelium of vessels leaving & entering heart



Two features from this diagram that you need to know: **ligamentum arteriosum and the rough concept of coronary arteries and veins (more about the coronary arteries and veins later).**

<u>Atria</u>: the receiving chambers

Small, thin-walled chambers; contribute little to propulsion of blood

Auricles: appendages that increase atrial volume

<u>Right atrium:</u> receives deoxygenated blood from body

Anterior portion is smooth-walled

Posterior portion contains ridges formed by pectinate muscles

Posterior and anterior regions are separated by *crista terminalis*

Thinner than the ventricles: small, thin-walled - need only convey blood by ventricles

<u>Three veins empty into right atrium:</u>

Superior vena cava: returns blood from body regions above the diaphragm

Inferior vena cava: returns blood from body regions below the diaphragm

Coronary sinus: returns blood from coronary veins

<u>Left atrium:</u> receives oxygenated blood from lungs

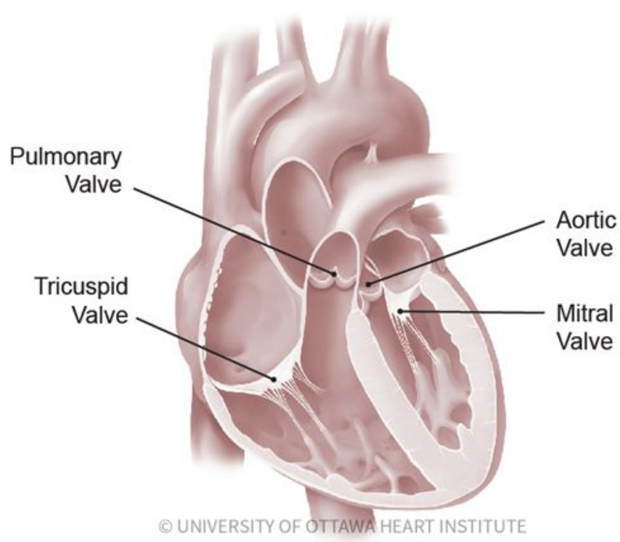
Pectinate muscles found only in auricles

Four pulmonary veins return blood from lungs

<u>Ventricles: </u>the discharging chambers

•Make up most of the volume of heart
•Right ventricle: most of anterior surface
•Left ventricle: posteroinferior surface
•Trabeculae carneae: irregular ridges of muscle on ventricular walls
•Papillary muscles: project into ventricular cavity
•Anchor chordae tendineae that are attached to heart valves
•Thicker walls than atria
•Actual pumps of heart
•Right ventricle
•Pumps blood into pulmonary trunk
•Left ventricle
•Pumps blood into the aorta (largest artery in body)

<u>Heart Valves:</u> ensure unidirectional flow



Atrioventricular valves (AV)
Tri- and Bi-cuspid
Semilunar valves (SL):
Pulmonary and Aortic

<u>Valves:</u>

Ensure unidirectional blood flow through heart

Open and close in response to pressure changes

Two major types of valves

Atrioventricular valves located between the atria and ventricles

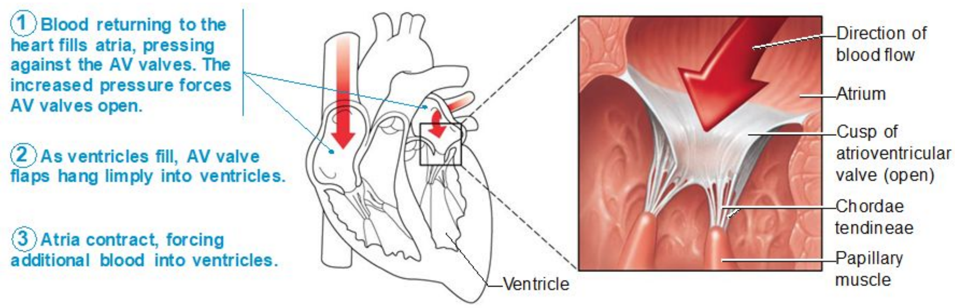
Semilunar valves located between ventricles and major arteries

No valves are found between major veins and atria; not a problem because:

Inertia of incoming blood prevents backflow

Heart contractions compress venous openings

Heatbeat is due to the opening and closing of valves: *The sound is associated with valve closing.*



(a) AV valves open; atrial pressure greater than ventricular pressure

b) **AV valves closed;** atrial pressure less than ventricular pressure

SL opening:

As ventricles contract and intraventricular pressure rises, blood is pushed up against semilunar valves, forcing them open.

SL closing:

As ventricles relax and intraventricular pressure falls, blood flows back from arteries, filling the cusps of the semilunar valves and forcing them to close.

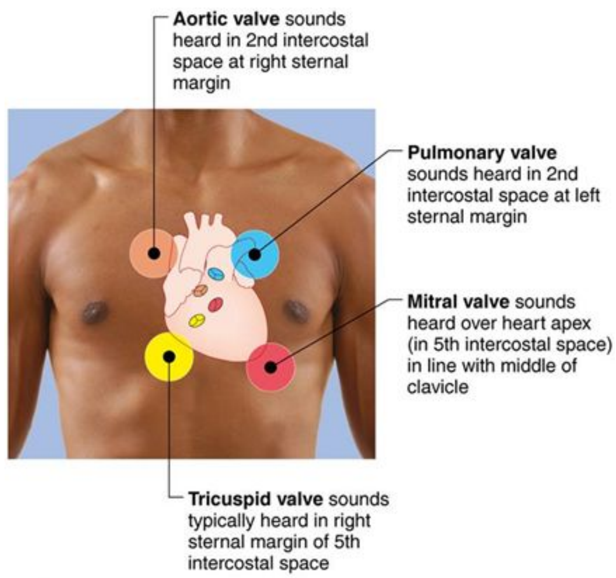
Heart sounds are associated with valves:

•Two sounds (lub-dup) associated with closing of heart valves

–First sound is closing of AV valves at beginning of ventricular systole

–Second sound is closing of SL valves at beginning of ventricular diastole

–Pause between lub-dups indicates heart relaxation



Problems with valve integrity - undergo a lot of stress

<u>Why do problems occur?</u>

The valves must sustain 80 million beats (give or take) a year

<u>What happens when something goes wrong?</u>

Two conditions severely weaken heart:

Incompetent valve

Blood backflows so heart repumps same blood over and over

Valvular stenosis (stenotic valve)

Stiff flaps that constrict opening

Heart needs to exert more force to pump blood

<u>How do we fix it?</u>

Defective valve can be replaced with 1) mechanical, 2) animal, or 3) cadaver valve

What about when there are problems?

Heart murmurs: abnormal heart sounds heard when blood hits obstructions

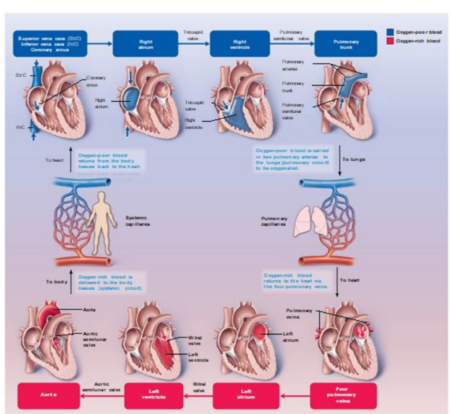
Usually indicate valve problems

Incompetent (or *insufficient*) valve (murmur): fails to close completely, allowing backflow of blood

Causes swishing sound as blood regurgitates backward from ventricle into atria

Stenotic valve (or aka valvular obstruction): fails to open completely, restricting blood flow through valve

Causes high-pitched sound or clicking as blood is forced through narrow valve



Equal volumes of blood are pumped to pulmonary and systemic circuits

Pulmonary circuit is short, low-pressure circulation

Systemic circuit is long, high-friction circulation

Anatomy of ventricles reflects differences

- Left ventricle walls are 3× thicker than right
  - Pumps with greater pressure

Pulmonary Side:

Right side of the heart

- Superior vena cava (SVC), inferior vena cava (IVC), and coronary sinus ®
- Right atrium ®
- Tricuspid valve ®
- Right ventricle ®
- Pulmonary semilunar valve ®
- Pulmonary trunk ®
- Pulmonary arteries ®
- Lungs

Systemic: Left side of the heart

- Four pulmonary veins ®
- Left atrium ®
- Mitral valve ®

Left ventricle ®

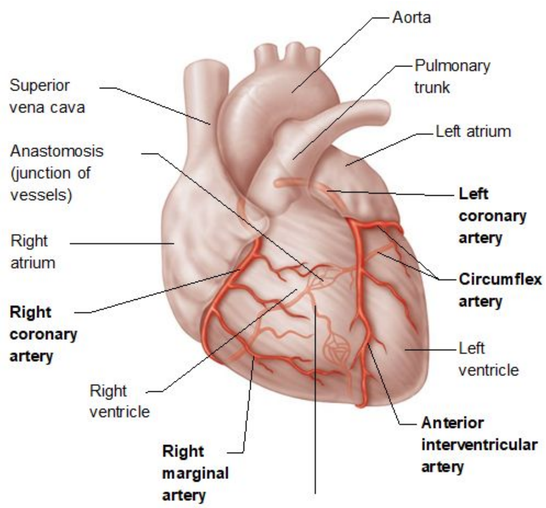
Aortic semilunar valve ®

Aorta ®

Systemic circulation

Coronary circulation: arteries and veins

Coronary arteries



***NEED TO KNOW ANASTOMOSIS (JUNCTIONS)**

Left coronary artery supplies interventricular septum, anterior ventricular walls, left atrium, and posterior wall of the left ventricle; has two branches:

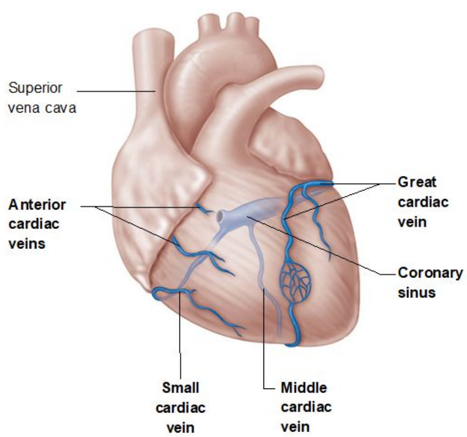
Anterior interventricular artery

Circumflex artery

Right coronary artery supplies the right atrium and right ventricle; has two branches:

- Right marginal artery
- Posterior interventricular artery

Coronary veins



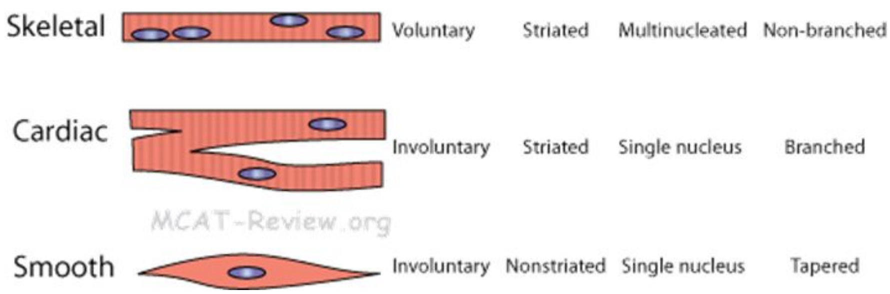
Cardiac veins collect blood from capillary beds

Coronary sinus empties into right atrium; formed by merging cardiac veins

- Great cardiac vein of anterior interventricular sulcus
- Middle cardiac vein in posterior interventricular sulcus
- Small cardiac vein from inferior margin

Several anterior cardiac veins empty directly into right atrium anteriorly

Properties of cardiac muscle



Cardiac muscle cells: striated, short, **branched**, fat, interconnected

One central nucleus (at most, 2 nuclei)

Contain numerous large mitochondria (25–35% of cell volume) that afford resistance to fatigue

Rest of volume composed of sarcomeres

Table 18.1 Key Differences between Skeletal and Cardiac Muscle

	SKELETAL MUSCLE	CARDIAC MUSCLE
Structure	Striated, long, cylindrical, multinucleate	Striated, short, branched, one or two nuclei per cell
Gap junctions between cells	No	Yes
Contracts as a unit	No, motor units must be stimulated individually	Yes, gap junctions create a functional syncytium
T tubules	Abundant	Fewer, wider
Sarcoplasmic reticulum	Elaborate; has terminal cisterns	Less elaborate; no terminal cisterns
Source of Ca^{2+} for contraction	Sarcoplasmic reticulum only	Sarcoplasmic reticulum and extracellular fluid
Ca^{2+} binds to troponin	Yes	Yes
Pacemaker cells present	No	Yes
Tetanus possible	Yes	No
Supply of ATP	Aerobic and anaerobic (fewer mitochondria)	Aerobic only (more mitochondria)

-heart contracts as a single unit

-Supply of atp requires oxygen

The heart relies almost exclusively on aerobic respiration

Cardiac muscle has more mitochondria than skeletal muscle so has greater dependence on oxygen

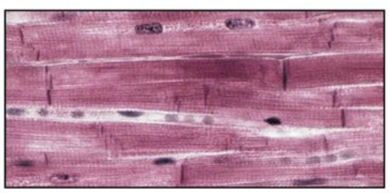
Cannot function without oxygen

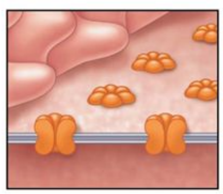
Skeletal muscle can go through fermentation when oxygen not present

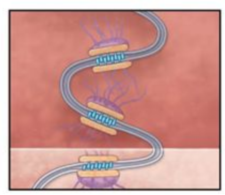
Both types of tissues can use other fuel sources

Cardiac is more adaptable to other fuels, including lactic acid, but must have oxygen

Microscopic anatomy of cardiac muscle







Intercalated discs are connecting junctions between cardiac cells that contain:

Desmosomes: hold cells together; prevent cells from separating during contraction

Gap junctions: allow ions to pass from cell to cell; electrically couple adjacent cells

Allows heart to be a functional syncytium, a single <u>coordinated</u> unit

There are 2 kinds of myocytes

Myocyte= heart cell

-*Contractile cells*:

- Responsible for contraction (that makes sense)

-*Pacemaker cells*:

•Non-contractile cells that spontaneously depolarize (self excitable)

•Initiate depolarization of entire heart

•Do not need nervous system stimulation, in contrast to skeletal muscle fibers

Electrical events of the heart

•Heart depolarizes and contracts without nervous system stimulation, although rhythm can be altered by autonomic nervous system

Central to heart functioning independently of the nervous system is the intrinsic conduction system

Intrinsic conduction system= Network of non-contractile (autorhythmic) cells

<u>Coordinated heartbeat is a function of:</u>

1. Presence of gap junctions
2. Intrinsic cardiac conduction system <-- This is very important

   Network of noncontractile (autorhythmic) cells (yep, same statement as above)

What is the function of the intrinsic system: Initiate and distribute impulses to coordinate depolarization and contraction of heart

Note:

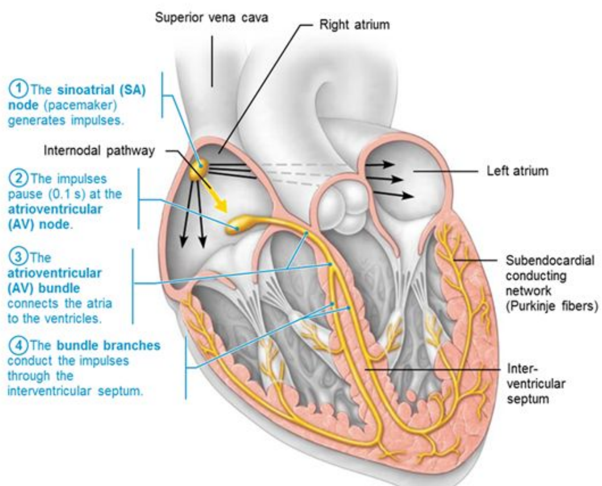
Tetanic contractions cannot occur in cardiac muscles

Cardiac muscle fibers have longer absolute refractory period than skeletal muscle fibers

•Absolute refractory period is almost as long as contraction itself

•Prevents tetanic contractions

•Allows heart to relax and fill as needed to be an efficient pump



Pacemaker cells are concentrated in a specific area called the SA node and are connected to (and part of) the intrinsic conduction system

Pacemaker = SA node

Path = 1. SA node -> 2. AV node -> 3. AV bundle ->4.bundle branches ->5.Purkinje Fibres

1.Sinoatrial (SA) node

•Pacemaker of heart in right atrial wall

•Depolarizes faster than rest of myocardium

•Generates impulses about 75×/minute (sinus rhythm)

•Inherent rate of 100×/minute tempered by extrinsic factors

•Impulse spreads across atria, and to AV node

2. Atrioventricular (AV) node

•In inferior interatrial septum

•Delays impulses approximately 0.1 second

•Because fibers are smaller in diameter, have fewer gap junctions

•Allows atrial contraction prior to ventricular contraction

•Inherent rate of 50×/minute in absence of SA node input

3.Atrioventricular (AV) bundle (bundle of His)

•In superior interventricular septum

•Only electrical connection between atria and ventricles

•Atria and ventricles not connected via gap junctions

4.Right and left bundle branches

•Two pathways in interventricular septum

•Carry impulses toward apex of heart

<u>5.Purkinje fibers - aka Subendocardial conducting network</u>

•Complete pathway through interventricular septum into apex and ventricular walls

•More elaborate on left side of heart

•AV bundle and subendocardial conducting network depolarize 30´/minute in absence of AV node input

•Ventricular contraction immediately follows from apex toward atria

•Process from initiation at SA node to complete contraction takes ~0.22 seconds

Defects in intrinsic conduction system may cause:

Arrhythmias: irregular heart rhythms

•Uncoordinated atrial and ventricular contractions

Fibrillation: rapid, irregular contractions

•Heart becomes useless for pumping blood, causing circulation to cease; may result in brain death

•Treatment: defibrillation interrupts chaotic twitching, giving heart “clean slate” to start regular, normal depolarizations

Ectopic focus

•Defective SA node may cause ectopic focus, an abnormal pacemaker that takes over pacing

•If AV node takes over, it sets junctional rhythm at 40–60 beats/min

•Extrasystole (premature contraction): ectopic focus of small region of heart that triggers impulse before SA node can, causing delay in next impulse

Heart has longer time to fill, so next contraction is felt as thud as larger volume of blood is being pushed out

Can be from excessive caffeine or nicotine

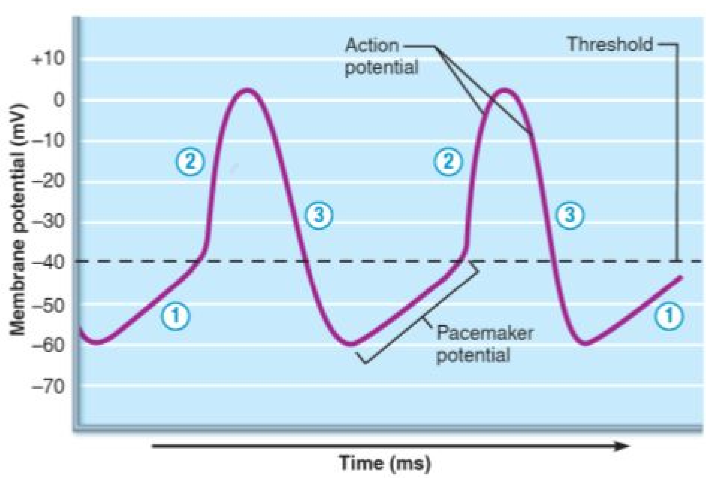
Heart block - AV node is defective

•Few impulses (partial block) or no impulses (total block) reach ventricles

•Ventricles beat at their own intrinsic rate; Too slow to maintain adequate circulation

•Treatment: artificial pacemaker, which recouples atria and ventricles

Action potential is initiated by pacemaker cells



(1) **Pacemaker potential** This slow depolarization is due to both opening of Na^+ channels and closing of K^+ channels. Notice that the membrane potential is never a flat line.

(2) **Depolarization** The action potential begins when the pacemaker potential reaches threshold. Depolarization is due to Ca^{2+} influx through Ca^{2+} channels.

(3) **Repolarization** is due to Ca^{2+} channels inactivating and K^+ channels opening. This allows K^+ efflux, which brings the membrane potential back to its most negative voltage.

Cardiac pacemaker cells (you find these cells in the SA node) have unstable resting membrane potentials called pacemaker potentials or prepotentials

Three parts of action potential

1. Pacemaker potential: K^+ channels are closed, but slow Na^+ channels are open, causing interior to become more positive

2. Depolarization: Ca^{2+} channels open (around -40 mV), allowing huge influx of Ca^{2+}, leading to rising phase of action potential

3. Repolarization: K^+ channels open, allowing efflux of K^+, and cell becomes more negative

PRACTICE QUESTIONS

Which of the following statements is false:

A) The apex of the heart points down and to the left

B) Cardiac tissue is rich in mitochondria

C) Pacemaker cells are concentrated in the AV node

D) Blood enters the heart at the left atrium

Which of the following is true of the atria

A) They don't contract

B) The two atria contract in sequence

C) The right atria receives blood from the lungs

D) They are receiving chambers

E) None of the above

F) All of the above

True or false: Mature red blood cells are actively transcribing genes

True or false: Heart sounds are associated with value opening?

True or false: Oxygenated blood flows into the left atrium

Summary

We learned about the structure of the heart, both inside and out. Using this we were able to trace the path of a RBC through the heart. We then dived into the structure and function of cardiac cells as a lead-in to the intrinsic conduction system.