Overview of Cardiovascular System/Heart

- Pulmonary & Systemic Circuits - heart is 2 pumps
  - Pulmonary - from right V --> Pulmonary trunk --> pulmonary arteries - lungs --> pulmonary veins --> left A
Overview of Cardiovascular System/Heart

- Pulmonary & Systemic Circuits - heart is 2 pumps
  - Systemic - left V --> aorta --> other arteries --> veins --> superior & inferior vena cava --> right A
Overview of Cardiovascular System/Heart

• Position & Size of Heart
  – Approximately the size of your fist - ~ 9cm wide, 13 cm from base to apex, 6 cm from anterior to posterior; weighs about 300 g.
Overview of Cardiovascular System/Heart

• Position & Size of Heart
  – Location
    • Superior surface of diaphragm
    • In mediastinum of thoracic cavity
  • Left of the midline
Overview of Cardiovascular System/Heart

- Position & Size of Heart
  - Location
    - Anterior to the vertebral column, posterior to the sternum
Overview of Cardiovascular System/Heart

• **Pericardium** – a double-walled sac around the heart.
  – Protects and anchors the heart [to diaphragm & sternum]
• Prevents overfilling of the heart with blood
Overview of Cardiovascular System/Heart

• **Pericardium** – a double-walled sac around the heart.
  – Protects and anchors the heart [to diaphragm & sternum]
• Allows for the heart to work in a relatively friction-free environment
Pericardium – a double-walled sac around the heart.

– Composed of:
  • A superficial fibrous pericardium
Overview of Cardiovascular System/Heart

- **Pericardium** — a double-walled sac around the heart.
  - Composed of:
    - A deep two-layer serous pericardium
      - Parietal layer - internal surface of fibrous pericardium
      - Visceral layer covers surface of the heart
    - Separated by fluid-filled pericardial cavity
Gross Anatomy of the Heart

• Heart Wall
  – Epicardium – visceral layer of the serous pericardium
  – Myocardium – cardiac muscle layer for contraction of the heart
Gross Anatomy of the Heart

• Heart Wall
  – Endocardium – endothelial on inner surface
  – Fibrous skeleton of the heart – crisscrossing, interlacing layer of connective tissue in septa, around valves & in tissue between - insulates, reinforces.
Gross Anatomy of the Heart

• Chambers of the Heart
  – Consist of:
    • 2 atria plus auricles - thin walls
    • 2 ventricles - L thickest wall; trabeculae carne on surfaces
Gross Anatomy of the Heart

- Chambers of the Heart
  - Consists of:
    - Chamber boundaries marked by sulci
      - Coronary sulcus
    - Interventricular sulcus
Gross Anatomy of the Heart

• **Heart Valves** - ensure unidirectional blood flow through the heart.
  – Atrioventricular (AV) valves lie between the atria and the ventricles
    • AV valves prevent backflow into the atria when ventricles contract
Gross Anatomy of the Heart

• Tricuspid valve
  – Between right atrium and right ventricle

• Bicuspid valve (mitral valve)
  – Between left atrium and left ventricle
  – Chordae tendenae anchor flaps to the papillary muscles.
**Gross Anatomy of the Heart**

1. Blood returning to the heart fills atria, putting pressure against atrioventricular valves; atrioventricular valves forced open.
2. As ventricles fill, atrioventricular valve flaps hang limply into ventricles.
3. Atria contract, forcing additional blood into ventricles.

(a) Blood returning to the heart fills atria, putting pressure against atrioventricular valves; atrioventricular valves forced open.

(b) As ventricles fill, atrioventricular valve flaps hang limply into ventricles.

1. Ventricles contract, forcing blood against atrioventricular valve cusps.
2. Atrioventricular valves close.
3. Papillary muscles contract and chordae tendineae tighten, preventing valve flaps from evertting into atria.

- Direction of blood flow
- Atrium
- Cusp of atrioventricular valve
- Chordae tendineae
- Papillary muscle

- Atrium
- Cusps of atrioventricular valve
- Blood in ventricle

Atrioventricular valve open

Atrioventricular valve closed
Gross Anatomy of the Heart

– Semilunar Valves
  • Semilunar valves prevent backflow of blood into the ventricles
    – Aortic semilunar valve
      » lies between left ventricle and aorta
    – Pulmonary semilunar valve
      » lies between right ventricle and pulmonary trunk
Gross Anatomy of the Heart

- Blood flow through heart chambers
  - RA --> RV --> lungs --> LA --> LV --> systemic circ --> RA
Gross Anatomy of the Heart

• Coronary Circulation
  – Coronary circulation is functional blood supply to the heart muscle itself
  – Supplies 250mL/min = 5% of circulating blood
Gross Anatomy of the Heart

– Arterial Supply

• Ascending aorta ➔ left and right coronary arteries

• Left coronary artery ➔ interventricular artery [interventricular septum, ant. both ventricles] (anastomoses with posterior interventricular) [both ventricles, 2/3 of interventricular septum], and the circumflex artery [L atrium, posterior L ventricle]
Gross Anatomy of the Heart

- Right coronary artery [R. atrium, pacemaker] → posterior interventricular [post. both ventricles] & marginal arteries

- MI = necrosis of heart tissue – usually due to artery blockage
Gross Anatomy of the Heart

• Collateral routes ensure some blood delivery to heart even if major vessels are occluded.

• Diastolic flow > systolic [opposite other tissues]
Gross Anatomy of the Heart

• Coronary Circulation
  – Venous Supply
    • Coronary arteries ➔ cardiac veins ➔ coronary sinus ➔ right atrium
Superior vena cava
Anterior cardiac veins
Great cardiac vein
Coronary sinus
Small cardiac vein
Middle cardiac vein
Cardiac Conduction System & Cardiac Muscle

• Nerve Supply
  – ANS – Sympathetic speeds up, PS slows down.
  – Medulla – cardioaccelerator center → sympathetic nerves – T1-T5 → C ganglia → Cardiac nerves → ventricular myocardium ↑ force of contraction. Also ↑ coronary blood flow in sympathetic mode
Cardiac Conduction System & Cardiac Muscle

– Cardioinhibitory center – sends to vagus [to SA & AV nodes] ↓HR

– Steady firing of Vagus nerves to control HR = vagal tone
Cardiac Conduction System & Cardiac Muscle

• Conduction System
  – Autorhythmic cells:
    • Self excitable - Initiate action potentials
    • Found in SA node, AV node, AV bundle, R & L bundle branches, and Purkinje fibers [same order as signal passage].
Cardiac Conduction System & Cardiac Muscle

– Sequence of Excitation
  • Sinoatrial (SA) node $\rightarrow$ impulses about 75 times/minute
  • Action potentials $\rightarrow$ gap junctions through intercalated discs across atria=atria contract
Cardiac Conduction System & Cardiac Muscle

- AV node delays impulse ~ 0.1 second
- Impulse passes from atria to ventricles via the AV bundle [bundle of His – superior interventricular septum].
Cardiac Conduction System & Cardiac Muscle

• AV bundle splits into 2 *paths in interventricular septum* (= bundle branches)
  – Bundle branches carry impulse toward apex
  – Purkinje fibers carry impulse to apex & ventricular walls
- Superior vena cava
- Sinoatrial (SA) node (pacemaker)
- Internodal pathway
- Atrioventricular (AV) node
- Atrioventricular (AV) bundle (Bundle of His)
- Bundle branches
- Purkinje fibers
- Right atrium
- Left atrium
- Purkinje fibers
- Interventricular septum
Cardiac Conduction System & Cardiac Muscle

• Properties of Cardiac Muscle Fibers
  – Striated, short, fat, branched, and interconnected
  – Intercellular spaces filled with loose connective tissue with capillaries
Cardiac Conduction System & Cardiac Muscle

– Intercalated discs anchor cardiac cells together and allow passage of ions

– \( \text{Ca}^{2+} \) delivery – wider & fewer T-tubules; no triads
Cardiac Conduction System & Cardiac Muscle

• Metabolism of Cardiac Muscle
  – Almost exclusively aerobic
  – Myoglobin stores \( O_2 \), glycogen stores glucose
  – Extra large mitochondria [25% of cell]
Electrical & Contractile Activity

- Normal pattern triggered by SA node = sinus rhythm [70-80/min]
- Outside stimuli can cause firing from ectopic focus – usually AV node
Electrical & Contractile Activity

- **Arrhythmias** = uncoordinated contractions
  - Blocks - action potential propagation problem [damage to AV node].
  - Fibrillation - asynchronous contraction [control taken away from SA node].
• Pacemaker Physiology
  – Upon stimulation, Na\(^+\) enters and depolarization begins → opening of fast Ca channels → action potential → K channels open → K leaves
Electrical & Contractile Activity

• **Impulse Conduction**
  
  – Delay at AV node of 100msec [to enhance ventricular filling]

  – SA signal --> AV node in 0.05 sec

  – Ventricular myocardium conducts at 0.5 m/sec, but Purkinje, etc. are much faster
    
    • keeps the ventricles synchronous
Electrical & Contractile Activity

• Electrical Behavior of Myocardium
  – Cardiac Muscle Contraction
    • Heart muscle: differences from skeletal muscle
      – Stimulated by nerves and self-excitatable (automaticity) resting potential is -90mV
    – Contracts as a unit
Electrical & Contractile Activity

– Sequence
  • Upon stimulation, Na$^+$ enters and depolarization begins $\rightarrow$ opening of fast Ca channels $\rightarrow$ action potential
  • Depolarization stimulates release of Ca$^{2+}$ from SR
  • Calcium binds to troponin & opens site for myosin to attach to actin
Electrical & Contractile Activity

- Ca$^{2+}$ - 10-20% enters from extracellular space $\rightarrow$ stimulates sarcoplasmic reticulum to release the other 90%. Fast Ca$^{2+}$ channels only open when Slow Na+ channels are open.

- Has a long (250 ms) absolute refractory period [prevents tetanus]
Electrical & Contractile Activity

• Electrocardiogram
  – Electrical activity is recorded by electrocardiogram (ECG)
  – Typically attaches to wrists, ankles and 6 chest positions
Electrical & Contractile Activity

– P wave corresponds to atrial depolarization

– QRS complex corresponds to ventricular depolarization

– T wave corresponds to ventricular repolarization

– Arial repolarization record is masked by the larger QRS complex
SA node generates impulse; atrial excitation begins

Impulse delayed at AV node

Impulse passes to heart apex; ventricular excitation begins

Ventricular excitation complete
Electrical & Contractile Activity

– Intervals-time spans between waves
  • P-Q- time from beginning of atrial contraction to beginning of ventricular contraction
  • S-T-plateau phase of ventricular contraction
  • Q-T-from first of ventricular depolarization to end of ventricular repolarization
Electrical & Contractile Activity

– Interpretations:
  • Enlarged P --> atrial hypertrophy
  • Missing/inverted p --> SA damage
  • Enlarged Q --> MI
  • Enlarged R --> ventricular hypertrophy
Blood Flow, Heart Sounds & Cardiac Cycle

• Pressure & Flow
  – Fluid dynamics depend on pressure & resistance
  – Pressure is measured here in mmHg = Torr by the sphygmomanometer
Blood Flow, Heart Sounds & Cardiac Cycle

• **Heart Sounds**
  
  – Heart sounds (lubb-dupp) are associated with closing of heart valves
  
  – Two sounds in normal heart
    • 1st sound (lubb) occurs as AV valves close
    • 2nd sound (dupp) occurs when SL valves close
    • 3rd & 4th heard with rapid vent. filling & atrial contraction
Blood Flow, Heart Sounds & Cardiac Cycle

• Phases of **Cardiac Cycle**
  – Ventricular filling – mid-to-late diastole
    • Heart blood pressure is low as blood enters atria and about 80% flows into ventricles
  • AV valves are open; aortic and pulmonary are closed.
Blood Flow, Heart Sounds & Cardiac Cycle

- AV node fires → atrial depolarization → p wave and the atria contract → sends the remaining 20% into ventricles = atrial systole

- Atria then relax
Blood Flow, Heart Sounds & Cardiac Cycle

– Ventricular systole
  • ↑ ventricular pressure results in closing of AV valves
  • Isovolumetric contraction phase; ventricular pressure continues to ↑.
Blood Flow, Heart Sounds & Cardiac Cycle

– Isovolumetric relaxation – early diastole
  • Ventricles relax

• Backflow of blood in aorta and pulmonary trunk closes semilunar valves

• Continuing atrial filling and further relaxation opens AV valves
Cardiac Output (CO)

- CO is the amount of blood pumped by each ventricle in one minute

- \( CO = \text{heart rate (HR)} \times \text{stroke volume (SV)} \)
Cardiac Output (CO)

- HR is the number of heart beats per minute
- SV is the amount of blood pumped out by a ventricle with each beat
Cardiac Output (CO)

• Cardiac reserve is the difference between resting and maximal CO

• \[ CO \text{ (ml/min)} = HR \text{ (75 beats/min)} \times SV \text{ (70 ml/beat)} \]
  \[ = 5250 \text{ ml/min (5.25 L/min)} \]
Cardiac Output (CO)

• Heart Rate
  – Tachycardia >100 beats/min
  – Bradycardia < 60
  – Maximum CO usually around 160
Cardiac Output (CO)

• Factors affecting HR
  – ANS – Medulla oblongata - cardiac center with cardioacceleratory center [sympathetic] & cardioinhibitory center [parasympathetic]
  • Stimulation – increasing HR-sympathetic
  • Inhibition-parasympathetic [vagus]
Cardiac Output (CO)

– Chemical Regulation
  • Hormones
    – Epinephrine stimulates SA node
    – Thyroid hormones increase HR
  • Other
    – Caffeine inhibits cAMP clearance in 2nd messenger system
    – Nicotine stimulates catecholamine secretion
Cardiac Output (CO)

• Ion related:
  – Hypercalcemia – really slow rate; hypo --> rapid rate
  – Hypernatremia-blocks contractions
  – Hyperkalemia-can cause cardiac arrest; hypo makes cells harder to stimulate
Cardiac Output (CO)
Cardiac Output (CO)

• **Stroke Volume**
  
  – Preload, or degree of stretch, of cardiac muscle cells before they contract is the critical factor controlling stroke volume

  – The greater the stretching before systole, the greater the force of the contraction (**Frank-Starling Law**)
(a) Preload

(b) Afterload
Cardiac Output (CO)

• **Homeostatic Imbalances**
  – Congestive heart failure (CHF)
    • Pumping efficiency too low for body needs
      – is caused by: Coronary atherosclerosis, persistent high blood pressure, multiple myocardial infarcts, dilated cardiomyopathy (DCM)
Cardiac Output (CO)

• Developmental Aspects of the Heart
  – Fetal heart structures that bypass pulmonary circulation
    • Foramen ovale connects the two atria
    • Ductus arteriosus connects pulmonary trunk and the aorta
Cardiac Output (CO)

- **Atherosclerosis** - fatty deposits occur in vessels walls leading to occlusion.
  - Possible causes: Damage to vessel lining --> infiltration by phagocytic cells [absorb cholesterol & fats]
  - Platelets adhere to damaged lining --> clots
  - Related to too much LDL.
Cardiac Output (CO)

– Treatments:
  • Balloon angioplasty, laser angioplasty, coronary bypass surgery, stents