Electrical Activity of the Human Heart

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Outline

- Basic Facts about the Heart
- Heart Chambers and Heart Valves
- The Pulmonary Circulation
- The Systemic Circulation
- The Cardiac Cycle
- Muscle Types
- The Electric Cardiac Cycle
- The Electrocardiograph (ECG)
- ECG measurements
- Summary

What is the Heart?

- The heart is a very specialized muscle that pumps blood through the body, transporting oxygen, carbon dioxide, nutrients and waste.
- The heart is located in the middle of the chest, between the lungs. Its bottom is tipped to the left.

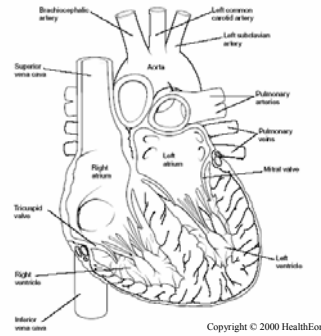
The Heart as a Pump

- The heart is like two pumps: one pumping blood into the body and one pumping blood out of the body.
- The heart is about as big as two clenched fists put together.
- The heart pumps blood in beats.

The Hard Work

Time	# of beats	Amount of blood pumped
< 1 second	1	70 milliliters
1 minute	~ 70	5 liters
1 day	100000	7200 liters
1 year	38 million	2.6 million liters
70 years	2.5 billion	184 million liters

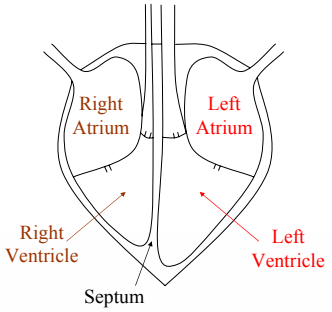
Anatomy of the Heart



Heart Chambers -1-

- Atrium is a chamber that pumps blood into the heart.
- Ventricle is a chamber that pumps blood out of the heart.
- The atria and the ventricles regulate blood flow by pumping blood in and out of the heart.

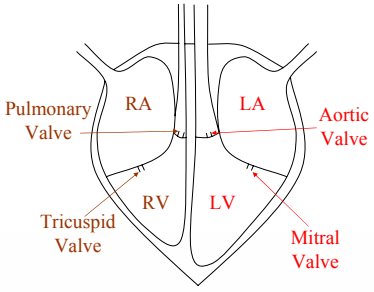
Heart Chambers -2-



Heart Valves -1-

- There are four valves in the heart.
- These are unidirectional valves that allow blood flow in only one direction.
- They prevent blood from flowing back to the chamber that it has just left.

Heart Valves -2-



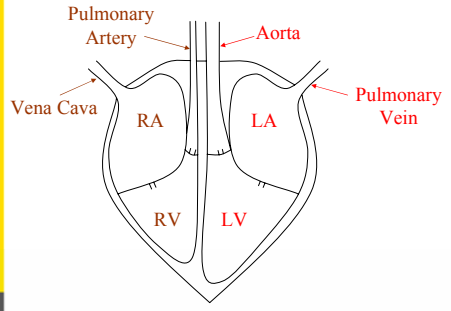
Heart Valves -3-

- The tricuspid valve and the mitral valve are also called A-V valves, because they separate an atrium from a ventricle.
- The pulmonary valve and the aortic valve are also called arterial valves, because they separate a ventricle from an artery.

Arteries and Veins -1-

- Artery is a blood vessel that delivers blood out of the heart. The two arteries of the heart are connected to ventricles.
- Vein is a blood vessel that delivers blood into the heart. The two veins of the heart are connected to atria.

Arteries and Veins -2-



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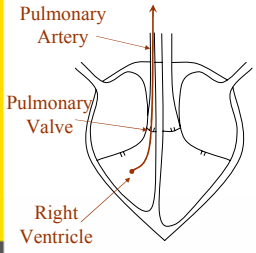
Pulmonary Circulation -1-



Deoxygenated (used) blood is pumped out of the right ventricle. It travels through the pulmonary valve into the pulmonary artery, leaving the heart.

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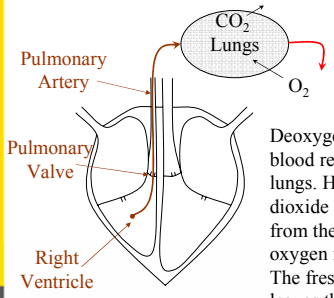
Pulmonary Circulation -2-



Deoxygenated (used) blood reaches the lungs. Here, carbon dioxide is removed from the blood and oxygen is added to it. The fresh blood leaves the lungs.

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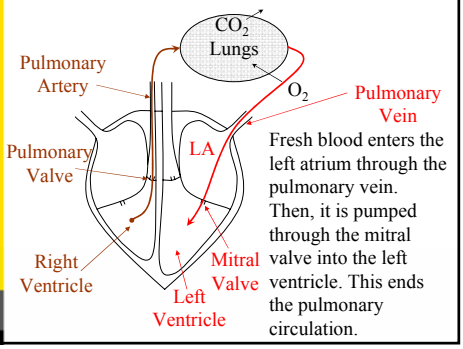
Pulmonary Circulation -3-



Fresh blood enters the left atrium through the pulmonary vein. Then, it is pumped through the mitral valve into the left ventricle. This ends the pulmonary circulation.

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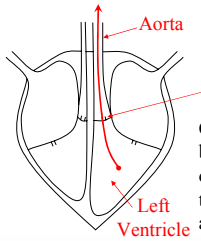
Systemic Circulation -1-



Oxygenated (fresh) blood is pumped out of the left ventricle. It travels through the aortic valve into the aorta, leaving the heart.

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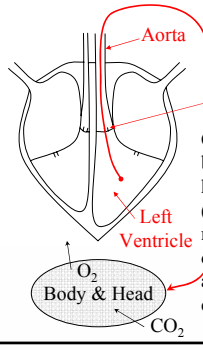
Systemic Circulation -2-



Oxygenated (fresh) blood reaches the head and the body (gut, kidney, muscles), where the oxygen in it is used and replaced by carbon dioxide.

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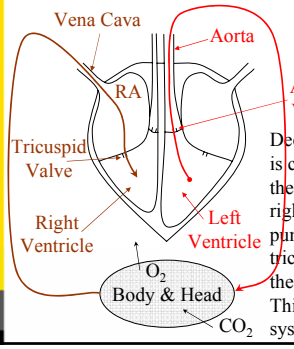
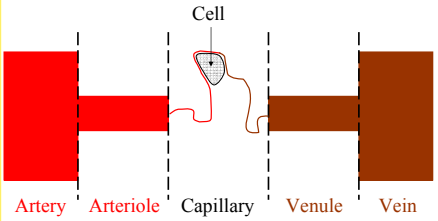
Systemic Circulation -3-



Deoxygenated blood is collected through the vena cava into the right atrium and is pumped through the tricuspid valve into the right ventricle. This ends the systemic circulation.

Blood Vessels

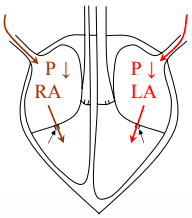


> 100000 km

Diffusion

- The exchange of molecules between cells and blood occurs at the capillary level.
- Capillaries are very small blood vessels with very thin walls.
- Oxygen and nutrients diffuse from the blood into the cell and carbon dioxide and waste diffuse from the cell into the blood.

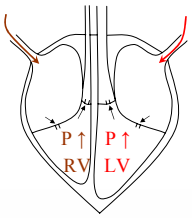
The Cardiac Cycle – Phase 1



<u>Atrial Contraction:</u>

1. Atria contract.
2. Atria empty out into the ventricles.
3. Atrial pressure drops.
4. A-V valves prepare to close.
5. Atria start filling.

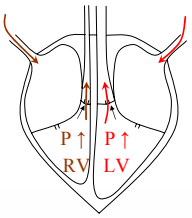
The Cardiac Cycle – Phase 2



<u>Isovolumetric Contraction:</u>

1. Ventricles contract.
2. Arterial valves are closed, no blood can be ejected.
3. Volume remains constant, pressure increases.
4. A-V valves close (First heart sound).
5. Atria continue to fill.

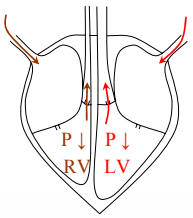
The Cardiac Cycle – Phase 3



<u>Rapid Ejection:</u>

1. Ventricular pressure continues to increase.
2. Arterial valves open.
3. Blood is rapidly ejected from the ventricles.
4. Atria continue to fill.

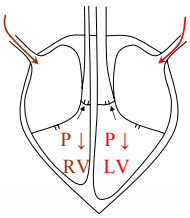
The Cardiac Cycle – Phase 4



Reduced Ejection:

1. Ventricles start to relax.
2. Ventricular pressure starts to drop.
3. Blood is slowly ejected from the ventricles.
4. Atria continue to fill.

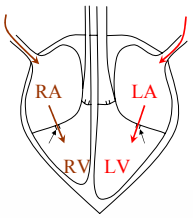
The Cardiac Cycle – Phase 5



Isovolumetric Relaxation:

1. Ventricles continue to relax.
2. Ventricular pressure continues to drop.
3. Arterial valves close (Second heart sound).
4. Atria continue to fill.

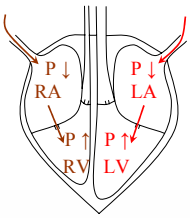
The Cardiac Cycle – Phase 6



Rapid Filling:

1. Atrial pressure exceeds ventricular pressure.
2. A-V valves open.
3. Blood flows rapidly from the atria to the ventricles.
4. Atria continue to fill.

The Cardiac Cycle – Phase 7



Reduced Filling:

1. Atrial pressure drops.
2. Ventricular pressure increases.
3. Blood flow from the atria to the ventricles slows down.
4. Atria continue to fill.

Muscle Types -1-

- Skeletal Muscle:
  - Fast-twitching
  - Voluntary control
  - Gets tired
  - Arms, legs etc.

Muscle Types -2-

- Smooth Muscle:
  - Slow-twitching
  - Involuntary control
  - Does not get tired
  - Stomach, bladder, blood vessels etc.

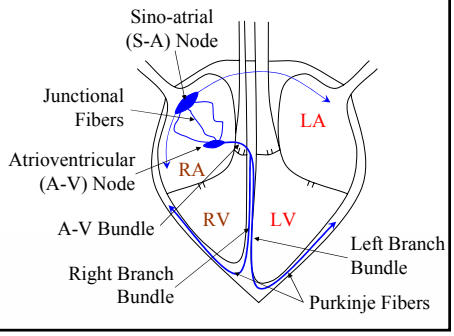
Muscle Types -3-

- Cardiac Muscle:
  - Built more like skeletal muscle, but works more like smooth muscle.
  - Involuntary control
  - Does not get tired
  - The heart!

Questions…

- The heart continuously goes through the cardiac cycle.
- The cardiac cycle is rather complex and consists of seven phases.
- How is each cardiac cycle started and controlled?

"Electrical Circuit" of the Heart



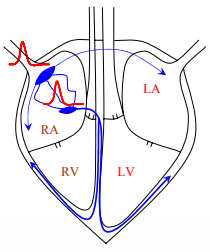
The S-A Node

- The S-A Node is the most important element in the electrical circuit of the heart.
- It starts the cardiac cycle by periodically generating action potentials without any external stimulation. (Therefore, it is said to be autorhythmic.)
- It is also known as the pacemaker of the heart.

The A-V Node

- The atrioventricular node periodically receives action potentials via the junctional fibers.
- The most important function of the A-V node is to regulate the timing of the ventricular contraction by delaying the action potentials.
- The delayed action potentials are spread over the ventricles to cause a contraction.

The Electrical Cycle

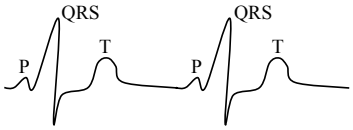


1. The S-A Node generates an action potential.
2. The action potential propagates in the atria and causes a contraction. It is also transmitted to the A-V Node.
3. The action potential is delayed at the A-V Node.
4. The action potential is transmitted to the ventricles and causes a contraction.

The Electrocardiogram

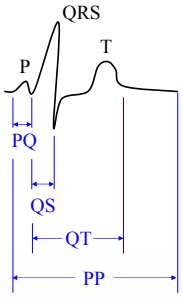
- The electrocardiogram (ECG) is a standardized way to measure and display the electrical activity of the heart.
- Physicians can diagnose problems with the heart by analyzing its ECG and comparing it to the ECG of a healthy heart.

ECG Waves



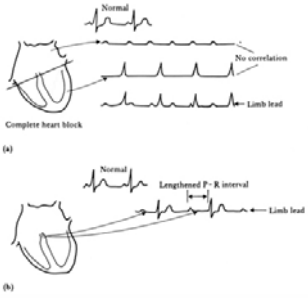
- The P Wave: Depolarization of the atria
- The QRS Complex: Depolarization of the ventricles
- The T Wave: Repolarization of the ventricles

ECG Intervals



- PQ: Time delay between atrial and ventricular depolarization
- QS: Duration of the ventricular depolarization
- QT: Duration ventricular depolarization-repolarization cycle
- PP: Duration of the cardiac cycle

A-V Blocks



Complete Heart Block

A-V Node not conducting at all, ventricles depolarizing independently

First-degree Heart Block

A-V Node introducing too much delay

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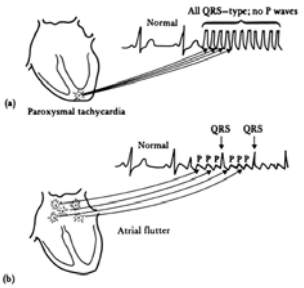
Heart Flutter



Paroxysmal Tachycardia

Ventricles depolarizing irregularly at a high rate

Atrial Flutter

Atria depolarizing irregularly at a high rate

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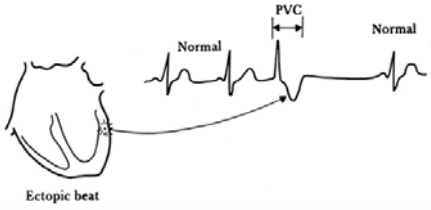
Extra V-Contraction

Extrasystole: An accidental pacemaker node causes an extra beat



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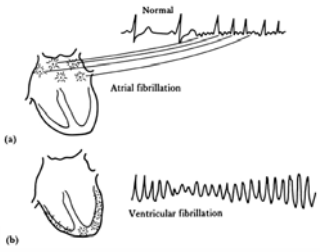
Fibrillation



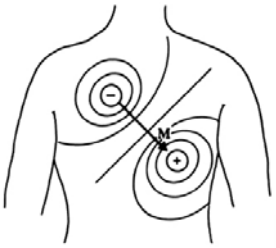
Atrial Fibrillation

Atria twitch irregularly

Ventricular Fibrillation

Ventricles twitch irregularly

Dipole Model of the Heart

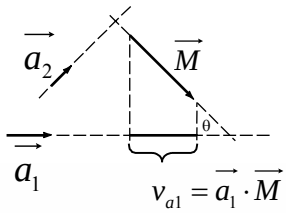


The Dipole Model

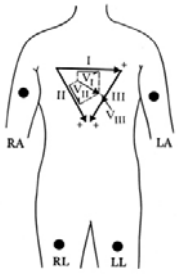
The electric field generated by this dipole is equivalent to the electric field generated by the heart at the peak of the QRS complex.

Lead Position

The location of electrodes relative to the dipole M is very important in ECG measurements.

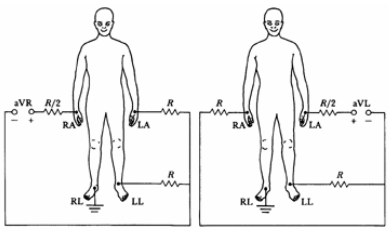


Limb Leads

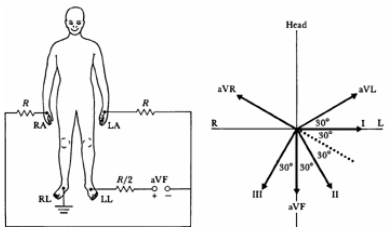


Lead	Relative angle
I: RA-LA	0°
II: RA-LL	60°
III: LA-LL	120°

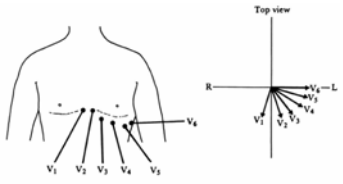
Augmented Leads -1-



Augmented Leads -2-



Chest Leads

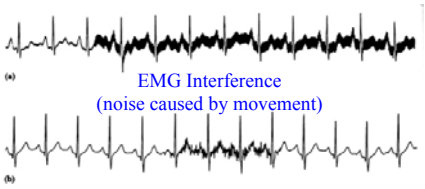


12-lead ECG

- Simultaneous measurements from:
  - Three limb leads
  - Three augmented limb leads
  - Six chest leads
- Process data from all leads to obtain ECG waveform

Noise in ECG

60 Hz Noise

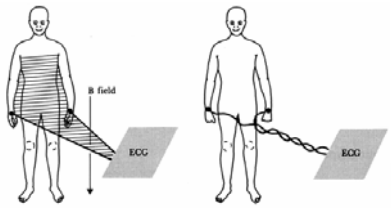


EMG Interference
(noise caused by movement)

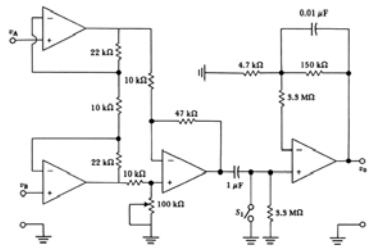
Electromagnetic Interference

Electromagnetic Interference

Twisted wires
→ No interference



An ECG Amplifier



The Electrocardiograph -1-

1. Protection Circuit
   - Protects electrocardiograph from high voltages
2. Lead Selector
   - Selects one or more leads to be recorded
   - Computer-controlled or manual operation
3. Calibration Signal
   - 1 mV precision signal to calibrate channels
4. Preamplifier
   - Multi-OpAmp differential amplifier stage
   - Gain control (automatic or manual)
5. Isolation Circuit
   - Protects patient against shock hazards
   - Reduces noise caused by leakage currents

The Electrocardiograph -2-

6. Driven Right Leg Circuit
   - Provides a reference at ground potential
   - Protects patient (The patient is *not* grounded.)
7. Driver Amplifier
   - AC – coupled amplifier stage
   - Bandpass filtering to optimize signal-to-noise ratio
8. Display and Memory System
   - Prints electrocardiogram on chart paper
   - Samples, digitizes and stores ECG in memory
9. Microcomputer
   - Automatic control of the electrocardiograph via user interface
10. Recorder-Printer
    - Records ECG along with patient information etc.

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Common Problems

1. Frequency Distortion
   - High-frequency distortion: Sharp corners are rounded off
   - Low-frequency distortion: Baseline is not horizontal
2. Saturation or Cutoff Distortion
   - Peaks are cut off because of improper internal voltage levels
3. Ground Loops
   - Potential difference between grounded points causes errors
4. Open Lead Wires
   - Disconnection of lead from electrode or of electrode from patient
   - Lead acts as an antenna and picks up electrical noise
5. Artifact from Large Electric Transients
6. Interference from Electric Devices

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Summary

- The heart consists of four chambers.
- There are two arteries exiting and two veins entering the heart.
- Blood flow in and out of the heart is controlled by four unidirectional valves.
- The heart pumps blood through the lungs for oxygenation (pulmonary circulation) and the body (systemic circulation).
- The heart works in cycles (cardiac cycle).
- The cardiac cycle is controlled by electric signals, which are generated in the S-A Node and propagate through the atria and ventricles.

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